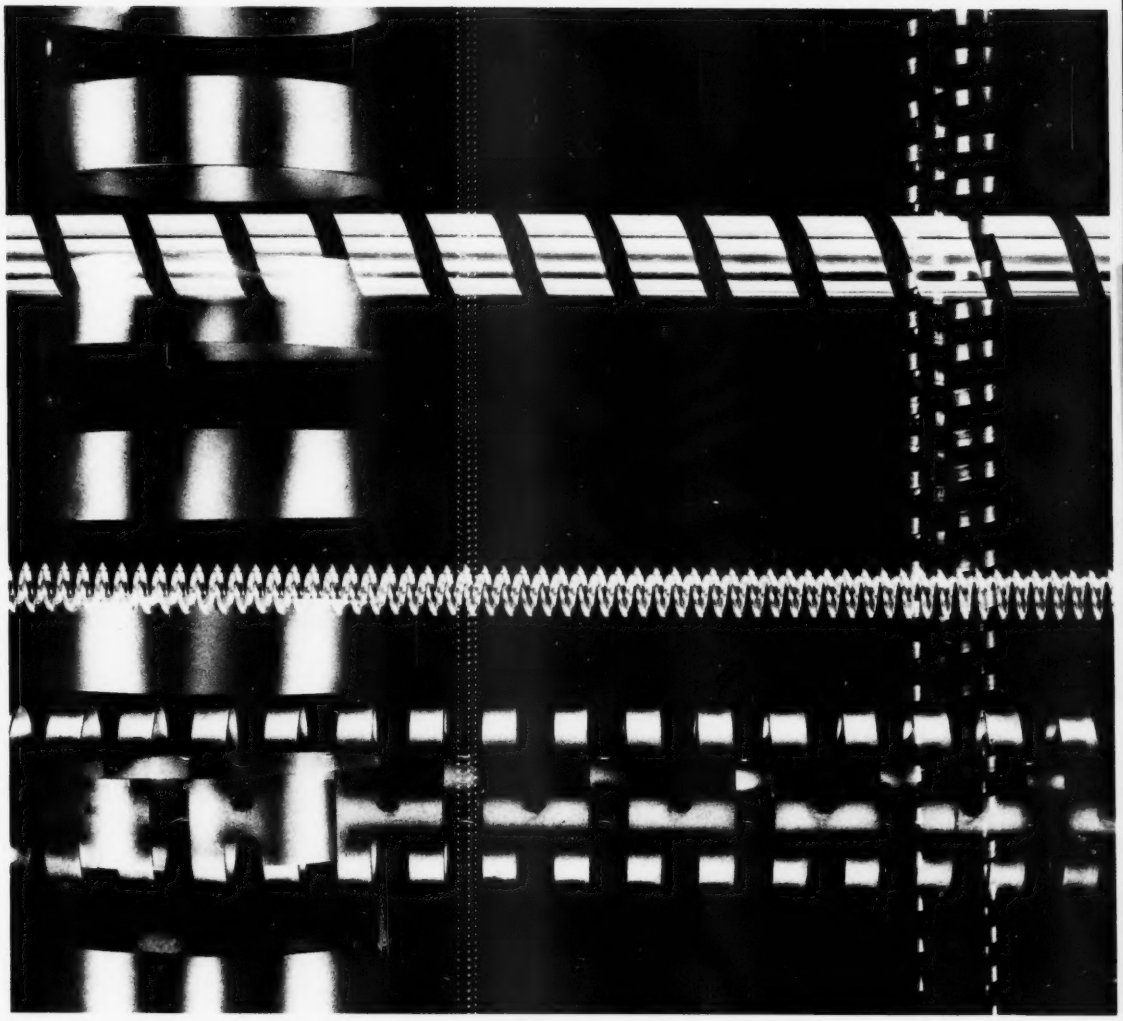
RAYTHEON

ELECTRONIC PROGRESS

NOVEMBER
DECEMBER 1958



Traveling Wave Tube Helices

In this issue: **AN/ TRC-27**

ELECTRONIC PROGRESS

Volume III November-December 1958 Number 3

RAYTHEON

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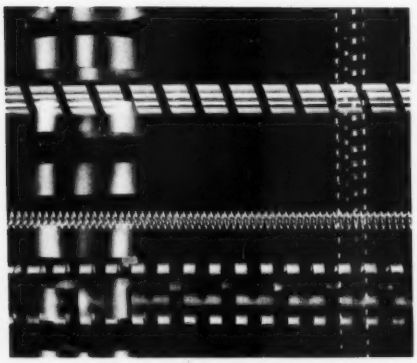
THE COVER



The cover photograph shows an array of traveling wave tube helices, simple and cross-wound. The helix is unique in its property of providing a slowed RF wave of nearly constant velocity over a wide frequency range.

Committees

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Infrared	*H. Letaw, Jr.*	Ultrasonic	*T. Hueter*
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Calendar

ENGINEERING SEMINARS

Seminars will be held weekly on Tuesdays at 5:20 P.M. at the Wayland Laboratory cafeteria. Security clearance will be required as indicated on the schedule. Personnel who do not hold picture badges should consult their security officers for attendance arrangements.

"Raytheon's Research and Engineering Program" I. A. Getting, Vice-President, Engineering and Research	Nov. 4	Confidential
"Electronic Materials" W. F. Leverton, Research Div.	Nov. 11	Unclassified
"Raytheon's International Operations" T. J. Kelly, International Div.	Nov. 18	Unclassified
"The Industrial Tube Division" E. J. Handly, Industrial Tube Div.	Nov. 25	Unclassified
"The Manufacturing Process—A Systems Approach" E. D. Graham, Vice-President, Manufacturing Services	Dec. 2	Unclassified
"Countermeasures" Countermeasures Group, Wayland Lab.	Dec. 9	Unclassified
"The Semiconductor Division, Its Products and Plans" F. M. Dukat, Semiconductor Div.	Dec. 16	Unclassified

Contents

The Traveling Wave Tube Amplifier ..... *E. C. Sheffler* 1
AN/TRC–27 Microwave Communications Relay ..... *J. Mofenson* 6
Radioisotopes: New Tool for Industry ..... *R. V. Peirce* 14
Publications and Papers 18
Raytheon Patent Procedures ..... *V. Harsha* 19

the Traveling Wave Tube Amplifier

E. C. Scheffler
Microwave and Power Tube Division

PRESENT day communications systems require the transmission of increasingly large volumes of information. Since the bandwidth of the system is a major factor in determining the rate of flow of information, it follows that wide frequency bands must be used to satisfy the increased demands. Transmission of a single black and white television signal, for example, requires a frequency band about 4 mc wide or about four times the bandwidth of the entire broadcast band. Because of the increased bandwidth requirements, the frequency spectrum which has been used for communication in the past is becoming more and more crowded. Fortunately, the microwave spectrum provides a great deal of new frequency space. The small part of the microwave spectrum in the wavelength range from 6.0 to 7.5 cm has a frequency range of 1000 mcs. Even this small portion is sufficient to transmit simultaneously many TV channels. To make full use of this frequency space, it would be desirable to have amplification over a corresponding bandwidth.

In the microwave frequency range, conventional vacuum tubes no longer amplify properly. At the higher frequencies, the period of one cycle of the radio frequency wave approaches the time it takes the electrons to travel from cathode to anode. This is known as the "transit time" effect. As a result the amplification of the tube decreases with increasing frequency, and above a frequency of a few thousand megacycles no useful gain can be obtained. Triodes have been built to operate up to 4000 mc, but their extremely small element size and spacing makes them difficult to fabricate and limits their power handling capability.

The klystron tube was the first practical amplifier in the microwave frequencies. The klystron is capable of providing high values of amplification, but because it uses resonant circuits, it has relatively narrow bandwidths.

The traveling wave tube amplifier is basically an extension of the klystron principle. The TWT, however, uses a non-resonant circuit element and, therefore, does not have the fundamental narrow bandwidth limitation of the klystron. The TWT is basically capable of high amplification over wide frequency ranges without requiring any mechanical tuning or the variation of any voltage or current to the tube.

Traveling wave tubes have been built to amplify over frequency bands of several thousands of megacycles and provide power amplification greater than 10,000 times or 40 db. The TWT appears to be more than adequate to handle today's bandwidth requirements. Thus the TWT is an important device that has found application in many microwave systems. Because the TWT is important, it is felt worthwhile to present a simple description of its theory, operation and characteristics.

GENERAL THEORY OF OPERATION

A traveling wave tube is an amplifier which in its bare essentials consists of an rf circuit surrounding an electron beam. Amplification is achieved through an interaction between the electron beam and a propagating wave on the rf circuit which, under certain conditions, will allow a transfer of energy from the beam to the rf circuit.

Basically, the conditions whereby this interaction of beam and rf wave is possible are:

1. The forward velocity of the wave progressing along the rf circuit, i.e., phase velocity, must be

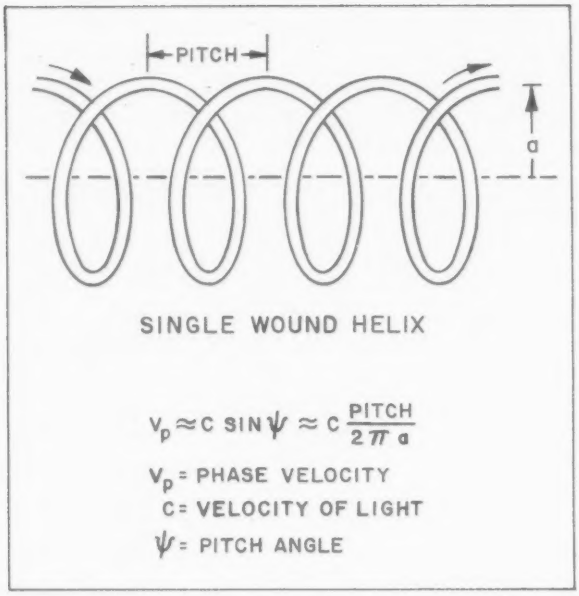

Figure 1

approximately the same as that of the electron beam.

2. The rf field of the wave on the circuit must extend into the region of the beam and have a strong component of electric field directed parallel to the beam.

A simple structure which satisfies these conditions is the helical transmission line, commonly called a helix. If an rf wave is introduced on the helix it will travel essentially at the velocity of light along the wire from which the helix is wound. Because of the helical path the wave is forced to follow, the actual forward progress of the wave along the axis of the helix is a fraction of the velocity of light. This so-called phase velocity is determined by the dimensions of the helix, its circumference and pitch. Having a phase velocity less than the velocity of light, this type of circuit is called a slow wave structure. It is shown in Figure 1. The rf fields associated with this slow wave extend outwards and inwards from the helix wire. It is the fields that extend inward into the region of the electron beam which produce the required interaction.

In practice, all TWT's incorporate the same basic components. These components are:

1. An electron gun to produce an electron beam.
2. An rf circuit which will propagate a microwave signal and permit interaction between the circuit wave and the electron beam.
3. Couplers to introduce and remove the wave from the circuit.
4. A collector to remove the electron beam energy.
5. An attenuator section to isolate the input and output sections of the circuit to prevent oscillations due to reflected signals.

Figure 2 shows a schematic view of the traveling wave tube.

The velocity of the electron beam, produced by the electron gun in Figure 2, is determined by the helix voltage according to the relationship $V = 5.93 \times 10^7 \times \sqrt{V_o}$ cm/sec when V_o is the helix voltage. A microwave signal introduced at the input end of the structure produces a wave progressing down the helix at the phase velocity. By adjusting the helix voltage, a condition is reached whereby the electron beam and the rf wave have the same forward velocity. This condition is called "synchronous velocity." The rf fields of the circuit wave now may influence the electron beam. The electrons which are in the influence of the retarding field region are slowed down and the electrons in the accelerating field region are speeded up. This effect is called velocity modulation. The fast electrons will overtake the slower ones producing a charge density modulation or "bunching" of the beam. The uniform beam thus becomes bunched to a slight extent after entering the circuit. As the loosely bunched beam travels down the helix, the electrons that are slowed down will induce an rf current on the circuit, adding

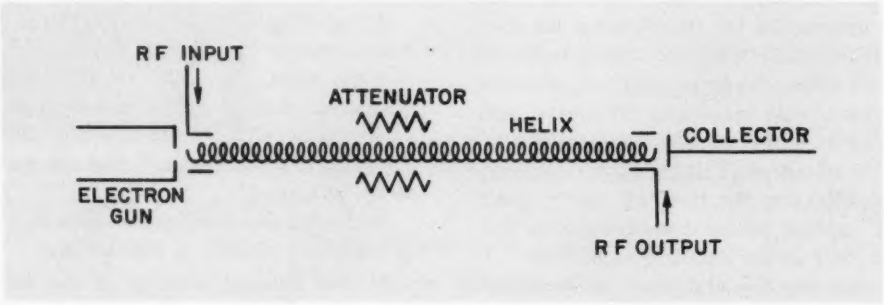

Figure 2

to the potential energy of the circuit at the expense of the kinetic energy of the beam. The rf field on the circuit will grow and the resulting increased field will further add to the beam bunching process while it is extracting energy from it. This process continues down the helix length, the beam being bunched tighter and the circuit wave extracting more and more power from the beam. In this process, those electrons that are accelerated absorb energy from the circuit. However, if the helix voltage is properly adjusted so that the velocity of the beam is slightly higher than that of the circuit wave, more electrons are decelerated than are accelerated so that a maximum transfer of energy from beam to circuit results. The increase in energy of the growing circuit wave is just balanced by a decrease in the average kinetic energy of the electron beam. Figure 3 shows the gain of a traveling wave tube as a function of helix voltage.

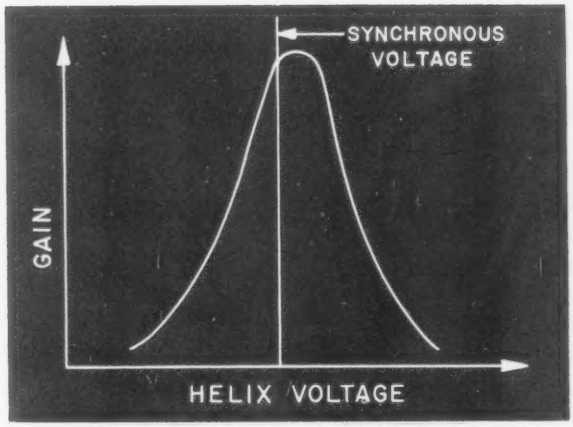

Figure 3

A condition is finally reached whereby the decelerated electrons are slowed down to such an extent that they fall behind the circuit wave and, in fact, enter an accelerating phase region. They will then begin to extract energy from the circuit. This condition is called saturation. If the interaction is continued beyond the saturation condition, the amplification process will decrease.

Because the amplitude of the circuit wave grows exponentially as it travels down the helix, the power gain of the tube in decibels is roughly proportional to the length of the helix expressed in circuit wavelengths.

This type of interaction has a great advantage over other microwave amplifiers in that the useful bandwidth is very great. A klystron amplifier is capable of producing high values of amplification, but because it generally makes use of a sharply resonant, high impedance tuned circuit, it is normally a narrow band device. The klystron uses such a circuit because interaction with the electron beam takes place over a short distance and consequently must develop high electric fields to have efficient interaction with the beam. In traveling wave interaction, by contrast, the electron beam is continuously under the influence of the circuit wave fields during its transit down the helix. Because the helix is a non-resonant circuit, the TWT will amplify all signals over the range of frequencies where the phase velocity of the circuit wave is nearly constant. A practical bandwidth of one octave is not uncommon for a TWT employing the helix slow wave structure. The low frequency limit of the interaction is determined by the number of wave lengths along the helix. That is, at low frequencies (long wave lengths) the helix becomes electrically short and there is insufficient travel distance in terms of wavelengths along the helix to produce the required energy transfer. At the high frequency limit, the fields of the circuit wave concentrate very close to the helix and away from the beam so that the interaction is reduced. In each instance the gain and power output fall below the desired level.

The TWT is generally operated in that range of frequencies where the velocity of the circuit wave is essentially independent of frequency. This range is called the "non-dispersive" region. Figure 4 shows the general characteristic curve of the phase velocity of the helix wave as a function of frequency. In region B of Figure 4, the non-dispersive region, the synchronous voltage is essentially independent of frequency. In this region, the helix voltage can be set to give the desired interaction between the circuit wave and beam and will provide interaction over a wide range of frequencies without adjustment.

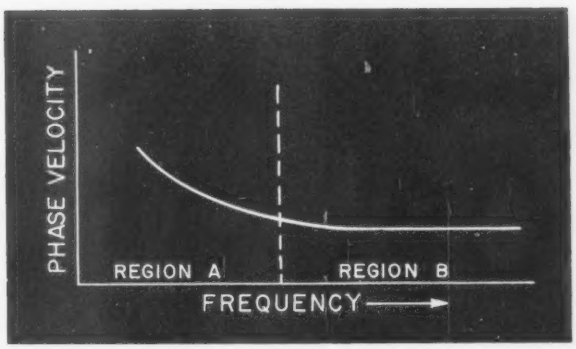

Figure 4

ELECTRON BEAM

The electron beam is formed in the electron gun of the tube and must travel down the entire length of the helix. Electrostatic forces that exist between electrons

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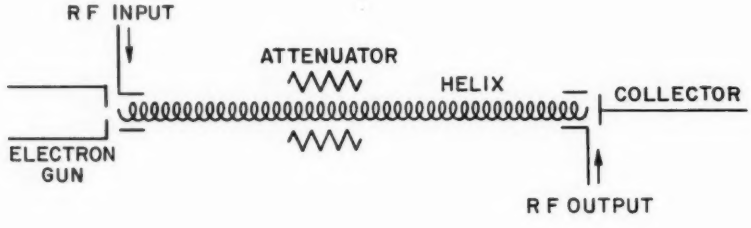

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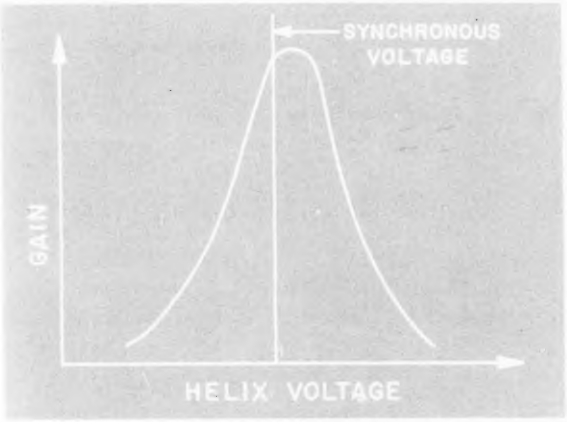

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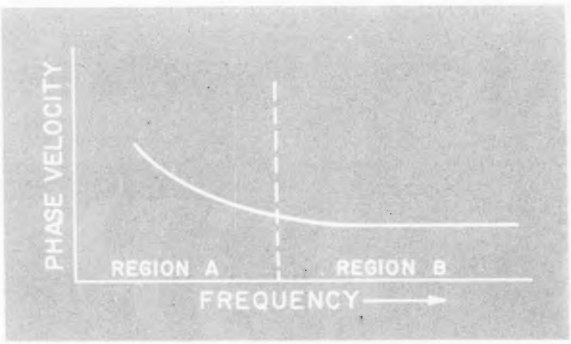

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in the beam tend to force the electrons apart and cause the beam to spread. Unless this is prevented, the beam will expand and hit the helix wire. When this happens, the electrons are of course no longer available for interaction with the circuit wave fields and amplification ceases. If the beam density is sufficiently large, the impinging beam will in fact melt the helix wire and destroy the helix circuit. Beam spreading is usually controlled by immersing the electron beam in a large uniform magnetic field directed along the beam axis. The magnetic field transforms any radial velocity components of the electrons, which would cause beam spreading, into angular velocities and thus imparts a spiral motion to these electrons. With the proper magnetic field value, the beam can be constrained within a constant diameter along the entire helix length. The magnetic fields required for beam focusing are produced by solenoids or permanent magnets.

TYPES OF CIRCUITS

The single-wound helix is the most extensively used slow wave propagating structure for traveling wave tubes. Such a helix has the greatest bandwidth, frequently two to one or more in frequency range, and is capable of large gain per unit length. It is a simple form to construct and can be easily analyzed mathematically. However, the helix is limited in its power handling capability.

Another slow wave structure commonly used for higher power traveling wave amplifier tubes is the contra-wound helix. This structure is essentially two helices of the same pitch and diameter, wound in opposite directions and connected at each crossover point. In this circuit, the wave velocity changes more rapidly with frequency (more dispersive) and the circuit wave is in synchronism with the electron beam over a bandwidth of about 15 to 30% of the center frequency. The contra-wound helix sacrifices bandwidth for increased power handling capability. Figure 5 shows one form of the contra-wound helix.

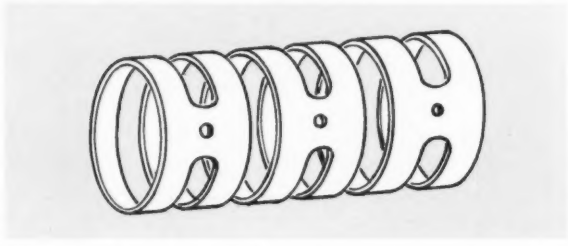


Figure 5

Another type of slow wave circuit used in some TWT's is the filter circuit. This structure usually takes the form of a waveguide with periodic internal irises, fins, or slots. These "loaded waveguides" have in general narrower bandwidths but will handle still larger rf power levels. Figure 6 shows several forms of the filter type circuit.

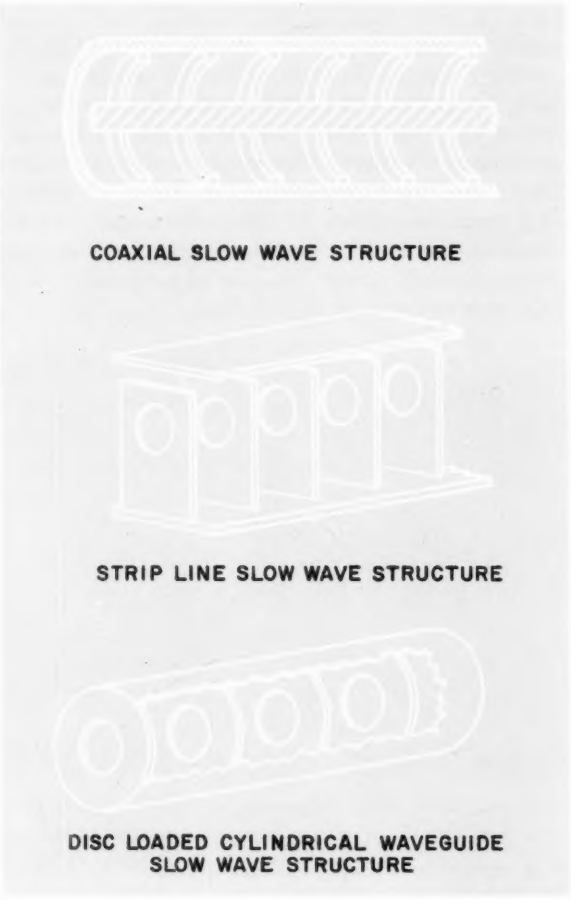


Figure 6

TYPES OF TRAVELING WAVE TUBES

Traveling wave tubes have been built to satisfy a large variety of applications. Tubes with gain of over 40 db (i.e., power amplification of over 10,000) are not uncommon and tubes having an operating bandwidth of over 8000 mcs are available. Traveling wave tubes have been constructed to operate at frequencies ranging from 100 to 50,000 mcs. The peak power output available from TWT's ranges from milliwatts to megawatts.

Some applications call for the amplification of weak signals and thus require that the noise level of the amplifier be extremely low. A family of TWT's called "low noise tubes" is available for this purpose. Noise

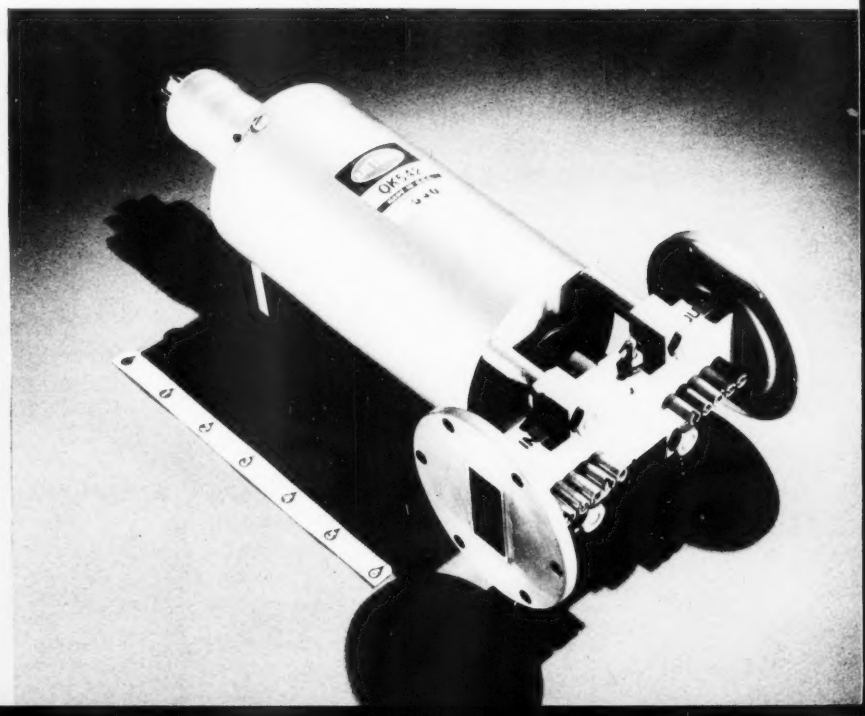
in a TWT will add to the input signal and consequently be amplified along with the signal. The primary source of noise is "shot-noise," which is a random variation of electron density across the electron beam. This noise appears on the beam as power which varies as a standing wave along the electron beam. In the low noise traveling wave tube, this noise power is reduced by using a special electron gun called a "velocity jump gun," having a particular combination of focusing electrodes. By introducing step changes of voltage along the gun, the noise current variations in the beam are reduced and the noise power in effect is de-amplified before it reaches the helix. Low noise TWT's have been built with noise figures of only a few db above thermal noise.

Some electronic countermeasures systems make use of the traveling wave tube to amplify noise signals for the purpose of jamming enemy radar. High power output is desired from such tubes and large bandwidths are needed to permit jamming of radar signals at any frequency being used.

Traveling wave tubes also are finding application in radar systems. Here a chain of amplifier tubes is used to produce pulses of high power. Large bandwidths are needed to permit operation over a wide range of frequencies, usually for the purpose of avoiding electronic countermeasures. Rapid changes in frequency can be accomplished electronically at low level and the output of such a master oscillator can be amplified to a power level useful for radar by a high gain amplifier chain.

Raytheon is actively engaged in several traveling wave tube development programs. The Special Tube Development Department of the Microwave and Power Tube Division is developing several high power traveling wave tubes for military applications. Details of this work are classified. The Beam Tube Research and Development Laboratory of Power Tube has at present three traveling wave tubes in development. The QK542 is a 5 watt, permanent-magnet-focused CW tube operating in the 5900 to 7400 mc frequency range. The QK746, which is in the design phase of development, is a low noise, permanent-magnet-focused tube designed principally as the driver tube for the QK542. Both of these tubes are being developed for commercial communication application. The third tube is the QK669, a 10 watt, permanent-magnet-focused CW tube operating in the 7000 to 8500 mc frequency band. This tube is being developed for military applications and is in the advanced stage of development. Figure 7 shows a photograph of the QK542 in its magnet and waveguide coupler package.

The traveling wave tube is a versatile device. It provides high amplification over a wide range of power levels, it has reasonably good efficiency and is capable of low noise figures. It has versatile modulation characteristics and will amplify uniformly over extremely wide frequency bands. Because of these features, the traveling wave tube has provided greater flexibility in many microwave systems. It is particularly well suited for communication application. Because of its high gain and wide bandwidth characteristics, the traveling wave tube makes possible the simultaneous amplification of many microwave signals. Future work on traveling wave tubes will be aimed at obtaining still greater bandwidth at high power levels and at further reduction in noise figures.



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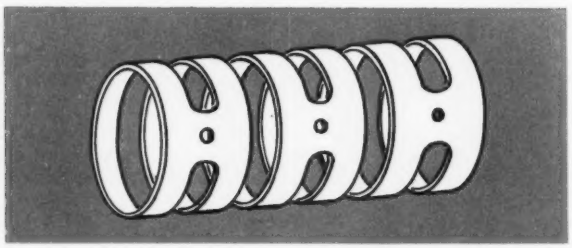

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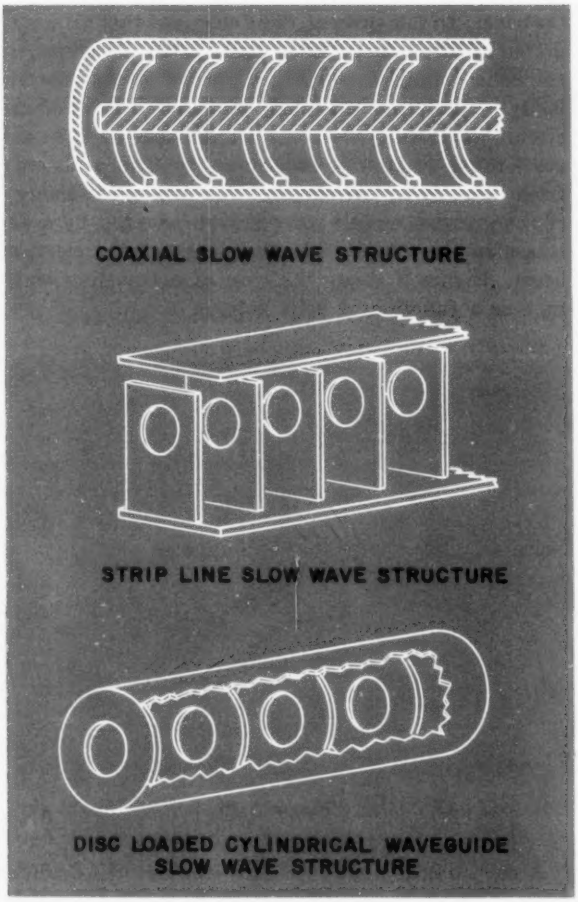

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in a TWT will add to the input signal and consequently be amplified along with the signal. The primary source of noise is "shot-noise," which is a random variation of electron density across the electron beam. This noise appears on the beam as power which varies as a standing wave along the electron beam. In the low noise traveling wave tube, this noise power is reduced by using a special electron gun called a "velocity jump gun," having a particular combination of focusing electrodes. By introducing step changes of voltage along the gun, the noise current variations in the beam are reduced and the noise power in effect is de-amplified before it reaches the helix. Low noise TWT's have been built with noise figures of only a few db above thermal noise.

Some electronic countermeasures systems make use of the traveling wave tube to amplify noise signals for the purpose of jamming enemy radar. High power output is desired from such tubes and large bandwidths are needed to permit jamming of radar signals at any frequency being used.

Traveling wave tubes also are finding application in radar systems. Here a chain of amplifier tubes is used to produce pulses of high power. Large bandwidths are needed to permit operation over a wide range of frequencies, usually for the purpose of avoiding electronic countermeasures. Rapid changes in frequency can be accomplished electronically at low level and the output of such a master oscillator can be amplified to a power level useful for radar by a high gain amplifier chain.

Raytheon is actively engaged in several traveling wave tube development programs. The Special Tube Development Department of the Microwave and Power Tube Division is developing several high power traveling wave tubes for military applications. Details of this work are classified. The Beam Tube Research and Development Laboratory of Power Tube has at present three traveling wave tubes in development. The QK542 is a 5 watt, permanent-magnet-focused CW tube operating in the 5900 to 7400 mc frequency range. The QK746, which is in the design phase of development, is a low noise, permanent-magnet-focused tube designed principally as the driver tube for the QK542. Both of these tubes are being developed for commercial communication application. The third tube is the QK669, a 10 watt, permanent-magnet-focused CW tube operating in the 7000 to 8500 mc frequency band. This tube is being developed for military applications and is in the advanced stage of development. Figure 7 shows a photograph of the QK542 in its magnet and waveguide coupler package.

The traveling wave tube is a versatile device. It provides high amplification over a wide range of power levels, it has reasonably good efficiency and is capable of low noise figures. It has versatile modulation characteristics and will amplify uniformly over extremely wide frequency bands. Because of these features, the traveling wave tube has provided greater flexibility in many microwave systems. It is particularly well suited for communication application. Because of its high gain and wide bandwidth characteristics, the traveling wave tube makes possible the simultaneous amplification of many microwave signals. Future work on traveling wave tubes will be aimed at obtaining still greater bandwidth at high power levels and at further reduction in noise figures.

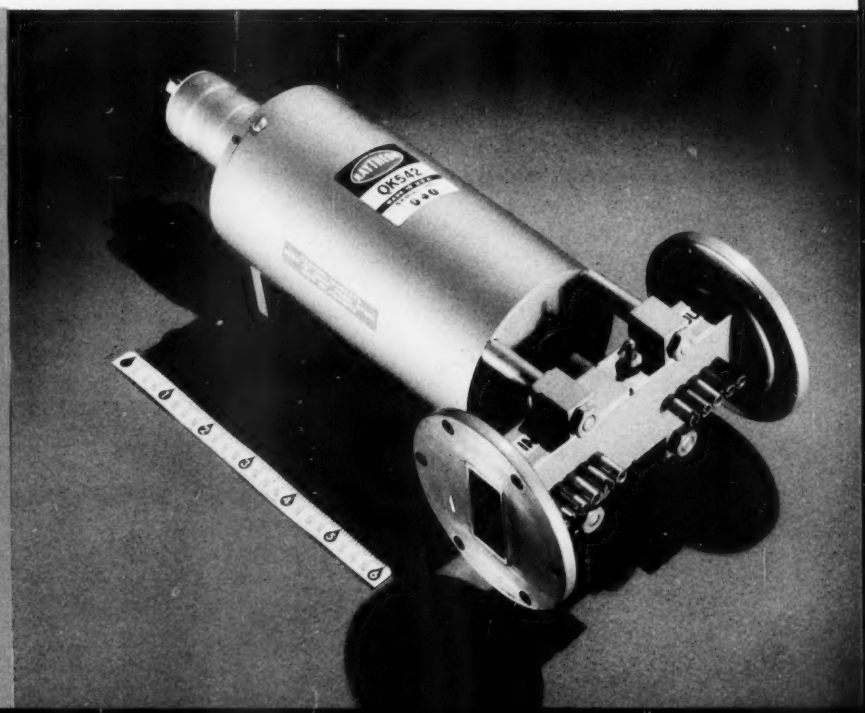


Figure 7

AN/TRC-27

Microwave Communications Relay

J. Mofenson
Wayland Laboratory

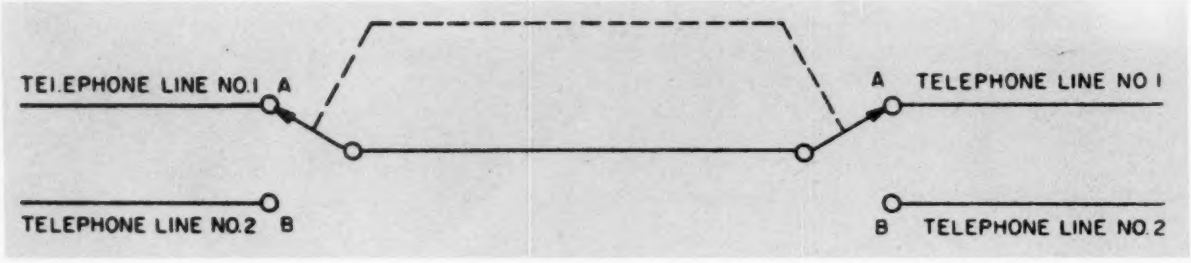
THE requirement of the U. S. Marine Corps for lightweight communications equipment suitable for use in forward combat areas has led to the development by Raytheon of the AN/TRC-27 microwave relay system. This system, designed and developed by the Communications Department of the Wayland Laboratory under BuShips' Contract NObsr-71035, is now in full production at the Waltham manufacturing plant.

A complete communications system using this equipment requires the use of two AN/TRC-27 terminals. These provide two-way microwave radio transmission for eight telephone circuits between them. The radio system uses the principles of time-division multiplexing (TDM) and pulse-position modulation (PPM). This method of multiplexing and modulation permits a lightweight radio set to possess advantages of high quality and low noise normally achieved only in much heavier equipment.

TIME-DIVISION MULTIPLEXING

The simultaneous transmissions of many channels on a common carrier is called multiplex radio transmission. The two basic methods of multiplexing are frequency-division multiplexing (FDM) and time-division multiplexing (TDM). In FDM, the separation between the channels is maintained by assigning each channel a different portion of the frequency spectrum. In TDM (the system used in the AN/TRC-27 equipment) separation is maintained by allocating a different interval of transmission time to each channel.

Consider the telephone system illustrated in Figure 1. In this system, switches S1 and S2 are synchronized so that when S1 is in position A, S2 is in position A. Similarly, both are in position B at the same time. Assume that a call is made on telephone line 1. This call is completed whenever the switches are in position A. The calls on line 2 are completed when the switches are in position B. Now assume that both lines are in use and that the switches are moving continuously back and forth between positions A and B. If



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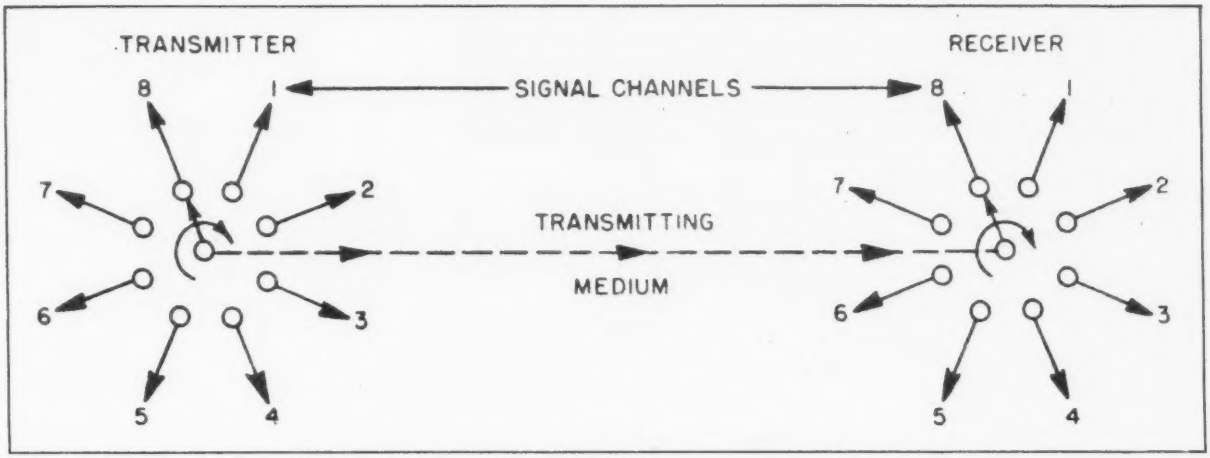


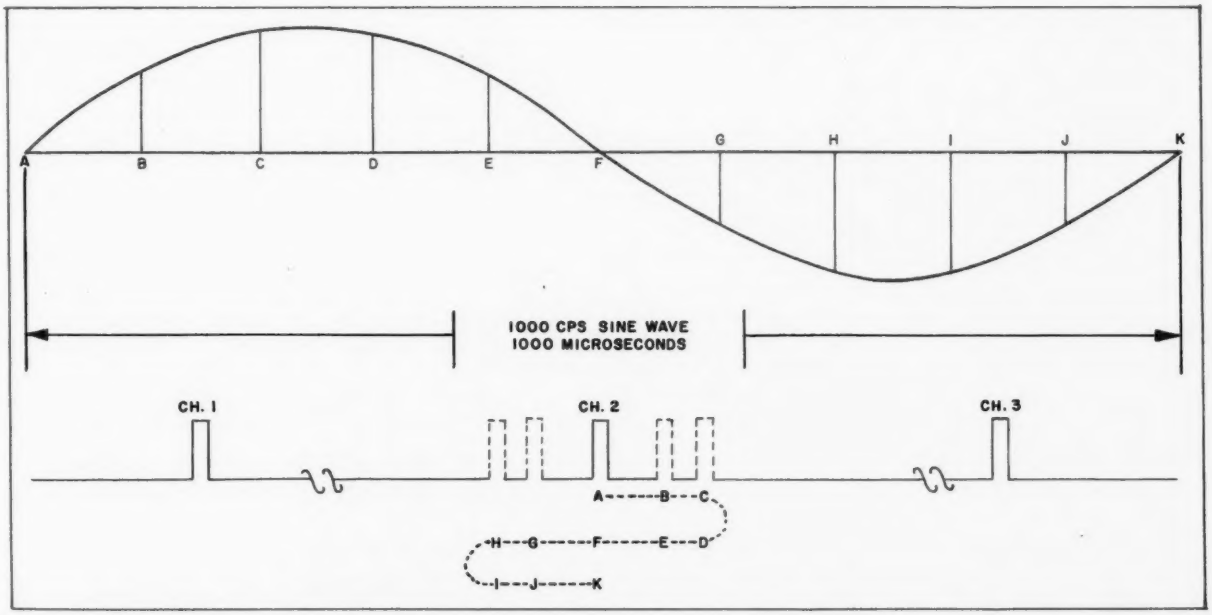
Figure 2

this switching is done at a slow rate, an appreciable part of the signal on each line is lost. As the rate of switching increases, less and less of the signal is lost. Finally, when the switching rate is extremely rapid, exceeding twice the rate of the highest frequency component of the speech signal, all information contained in that signal is preserved. (For an interesting discussion on sampling theory the reader is referred to "Modulation Methods" by H. S. Black, Van Nostrand and Company.) In this manner, two time-division multiplexed conversations can be held over one line at the same time. An eight-channel system is illustrated in Figure 2.

PULSE POSITION MODULATION

Unlike conventional radio communication equipments which transmit either amplitude- or frequency-modulated carriers, Radio Set AN/TRC-27 makes use of a technique of constant-amplitude pulse transmission called pulse-position modulation (PPM). With this technique, the amplitude of each instantaneous sample of an audio channel determines the relative position in time of the transmitted pulse. Figure 3 shows an example of how different time samplings of a 1000 cycle sine wave affect the relative positions of the transmitted pulse.

In the AN/TRC-27, the information coming from



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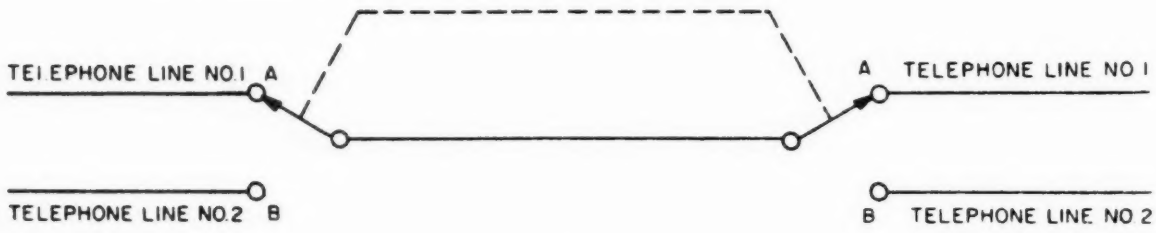

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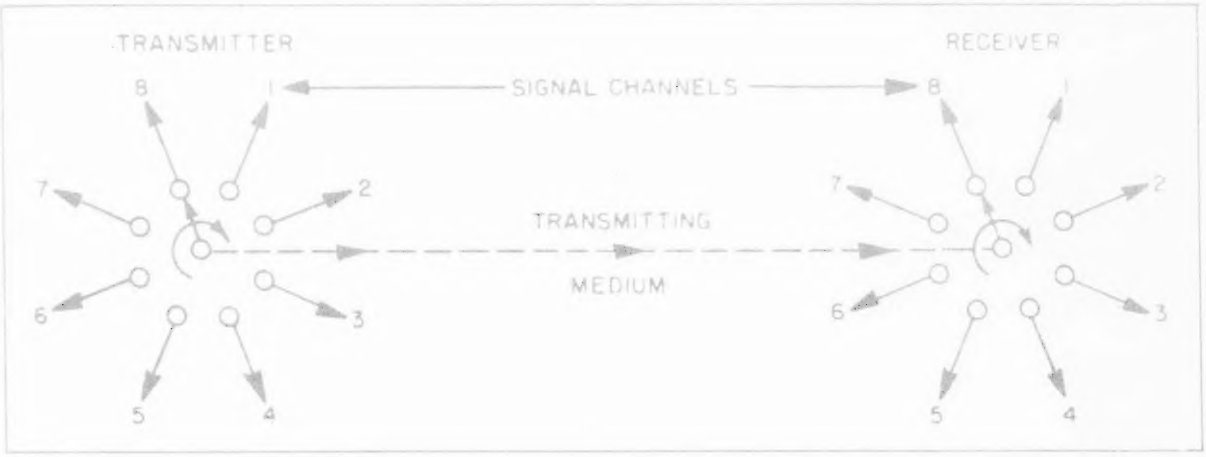

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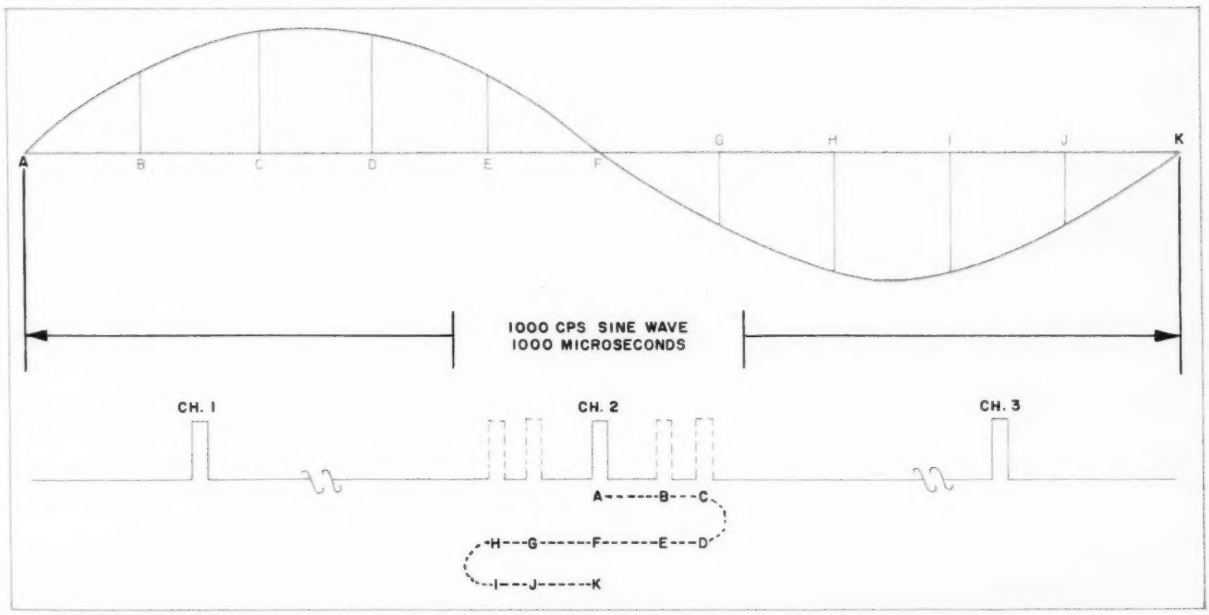


Figure 3

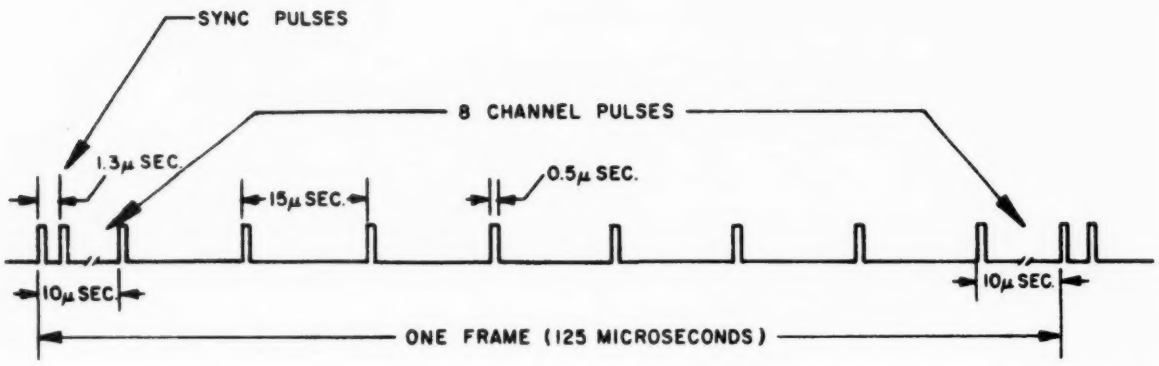


Figure 4

the eight audio channels is sampled sequentially by an electronic commutator and converted into a train of serially arranged pulses. Each of the pulses in this train may be considered as a sub-carrier whose relative position in time is caused to vary as the incoming voice information is sampled. If the sampling frequency is at least twice that of the incoming intelligence all information contained in the sampled signal is preserved. In the AN/TRC-27, the sampling frequency is 8000 cycles per second; the highest audio frequency required to be transmitted is 3500 cycles. Messages are transmitted by keying a microwave oscillator with this train of eight position-modulated pulses, each pulse representing one of the audio channels.

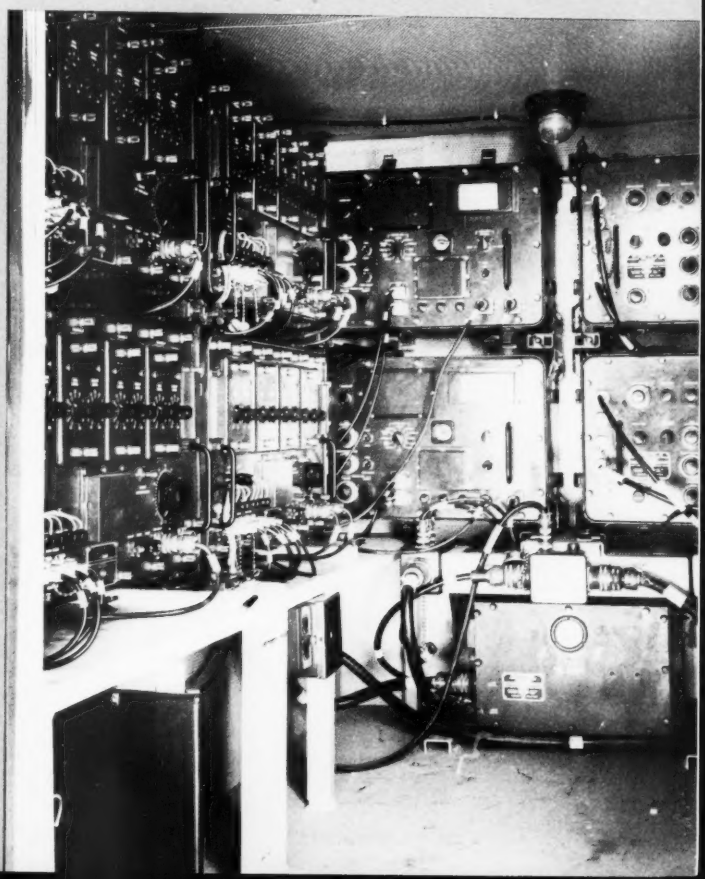
Each voice channel of the AN/TRC-27 occupies a 5 microsecond interval equal to 1/25 of the total frame time of 125 microseconds (see Figure 4). The 25th interval remaining in the frame is reserved for the placement of a distinctive pair of marker pulses which is required to re-establish the frame reference at the receiver. During the time allocated to a particular channel, the incoming voice-frequency signal is sampled at an 8 Kc rate and a pulse is transmitted. When no speech energy is applied to the input terminals of the channel, this pulse is positioned at the center of the channel time interval. Speech energy modulates the position of the pulse about the center within the channel interval in proportion to its amplitude at the sampling interval. The receiving terminal transforms the intelligence contained in the position of the pulses in each of the channels to an af voltage to be applied to its respective outgoing voice channel.

In the AN/TRC-27 system, the transmitted pulse is 0.5 microsecond long and the modulation deviation is ± 1 microsecond. Timing allocations for the pulses are arranged to integrate with another radio system. Pulses from multiplexer No. 1 are placed in the 5th, 11th, 17th, and 23rd intervals, while pulses from multiplexer No. 2 are placed in the 3rd, 9th, 15th, and 21st intervals. The synchronizing pulse pair is placed in the 25th interval.

Operating in the 4400-5000 mc band, the AN/TRC-27 (Figure 5) has the capability of handling eight two-way message circuits between two points separated by a line-of-sight path. Thus, it can provide all of the services of eight two-wire telephone circuits while having the advantage of being operable where terrain or tactical situation makes wire communication impractical. The AN/TRC-27 can operate either as a one-hop microwave system or as a multihop relay chain when properly connected. Facilities are provided to permit installation of the system in a jeep where it can operate from the jeep's power. In this application, the system nomenclature is AN/MRC-59 (Figure 6). In another mode of operation, four separate AN/TRC-27's can be installed in a truck-mounted shelter (AN/MRC-60) (Figure 7). In the latter application, the complete equipment is capable of being transported by helicopter from the deck of a transport vessel to a shore installation where the system can be set quickly into operation.

Figure 5

Figure 6



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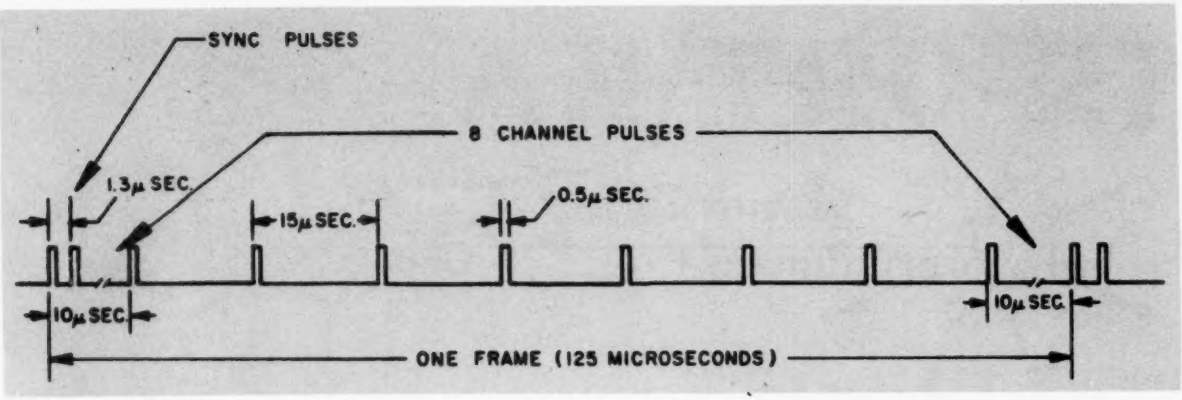

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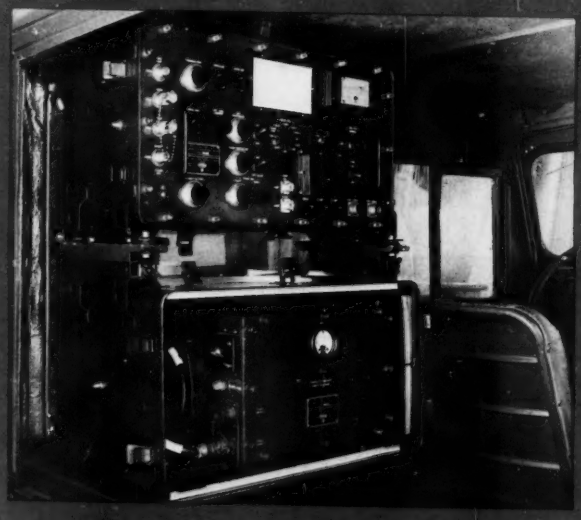

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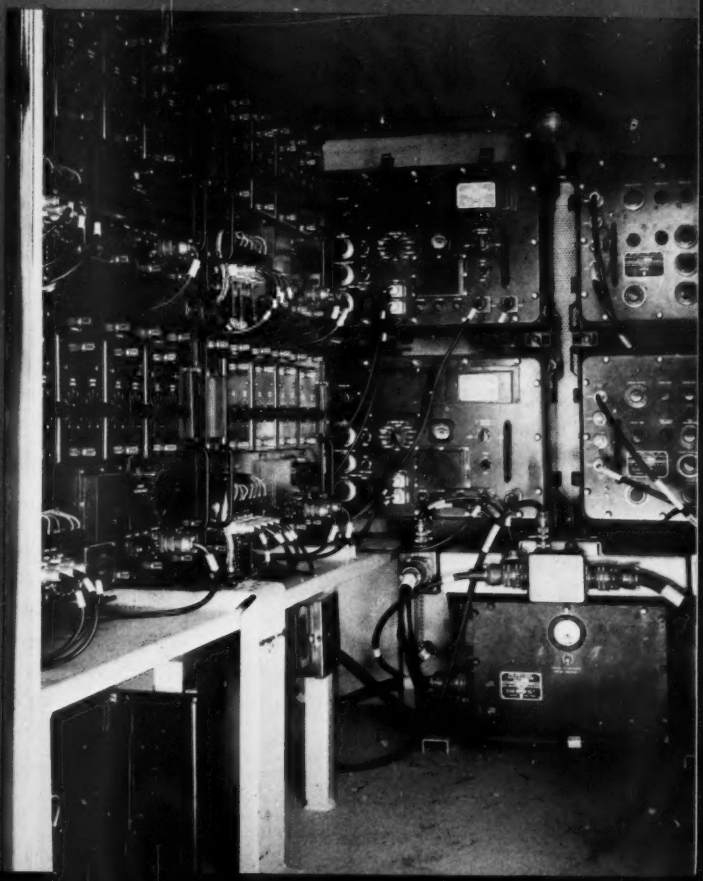

Figure 7

Photo courtesy of U.S.M.C.

Figure 8

The basic AN/TRC-27 equipment consists of a transmitter-receiver unit, two multiplexer units, an antenna unit, and one operating and one standby generator (Figure 8). Each of these units weighs approximately 55 pounds, is housed in a watertight transit case when packed for carry in the traveling condition, and is splash-proof in the operating condition. The system operates over a temperature range from −54°C to +65°C with up to 95% humidity, and is designed to meet all requirements of Bureau of Ships specification MIL-E-16400A.

SYSTEM PERFORMANCE

Calculations of system performance of the AN/TRC-27 were made to determine the power level of the received radio signal for various transmission ranges. The following calculation of space loss A_n, which will permit communication, is made by adding transmission gains and losses in decibels between transmitter and receiver stations:

$$A_n = 10 \log \frac{P_t}{P_n} - \left(\frac{C}{N}\right) - \overline{NF} + 2G - 2L$$

where $P_n = KTB = 1.38 \times 10^{-23} \times 300 \times 8.5 \times 10^6$ watts.

P_t is the transmitted pulse power which is 1.5 watts in this system. C/N is the ratio between pulse carrier power and average noise power at the receiver input at threshold (14 db). $\overline{NF}$ is the receiver noise figure, here equal to 13 db. G is the gain of one antenna (29 db), and L is the loss of one transmission line (5.3 db). Substituting these values gives A_n as 157.4 db (Figure 9).

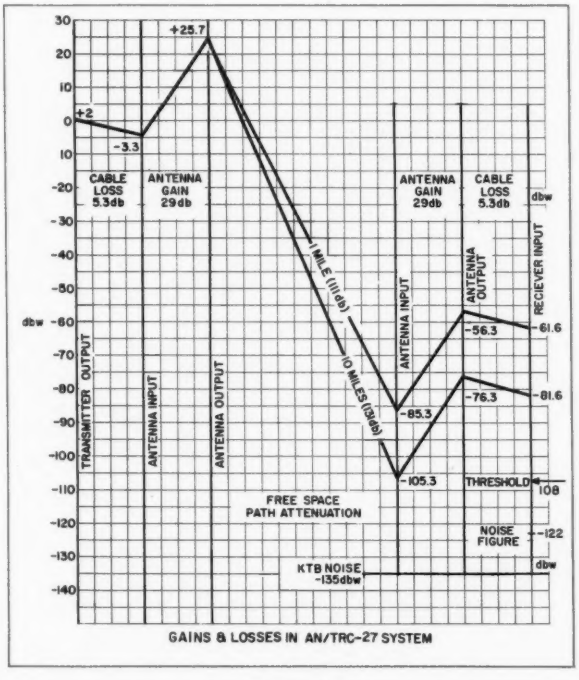

Figure 9

Using 157 db as the maximum allowable space attenuation between terminals, Table 1 shows the rf system margin for various ranges. (Free space attenuation is calculated at 5000 mc.) This rf fade margin is of paramount importance in determining the reliability of any microwave relay system. Changes of propagation characteristics of the atmosphere may be caused by any number of local meteorological phenomena. Effects of fog, temperature inversion, and ducting can increase path attenuation as much as 20-30 db. In addition, obstruction losses due to trees are frequently encountered in military situations. It is, therefore, desirable, in determining performance for a given range, to operate the system with a fade margin as high as possible. For normal usage, a 20-db fade margin permits reliable communications.

TABLE 1
SYSTEM MARGIN FOR VARIOUS RANGES

Range (miles)	Path Attenuation (db)	Fade Margin (db)
1	111	46
5	125	32
10	131	26
20	137	20
30	141	16
40	143	14
50	145	12

Once the received signal power exceeds the threshold level in the receiver, the normal PPM improvement and improvement due to the modification of the audio response by the characteristics of the type F1A telephone hand set must be calculated to determine the signal-to-noise performance at the receiving instruments. The threshold for PPM can be defined as the intersection of the tangents to two parts of the curve of audio s/n vs rf C/N (Figure 10). Communication of a usable variety does exist below the threshold; however, the rate of reduction of (s/n) audio with decreasing (C/N) at rf is about 4-6 db per db, and performance below this point proves erratic. For purposes of system calculation, the threshold point was chosen as 14 db.

Audio improvement in a Western Electric type F1A hand set compared to the flat 4-kc band of an 8-kc sampling system is 3.4 db. (This improvement is due to the non-uniform response of the hand set across the band so that noise components present in the less useful portion are greatly attenuated.) The video improvement using a 1 microsecond deviation for a pulse of 0.1 microsecond rise time is 20 db. Therefore, the total improvement in audio s/n, once threshold is reached, is 23.4 db. This figure added to the fade margin gives the normal audio s/n of the entire system. An examination of Figure 10 shows that the upper level for system s/n is limited at about 54 db. This limiting is due to the random jitter present on the leading edge of the rf transmitted pulse. The jitter is present because random noise causes an uncertainty in the starting time of the directly pulsed oscillator. This uncertainty is a limitation of such transmitters.

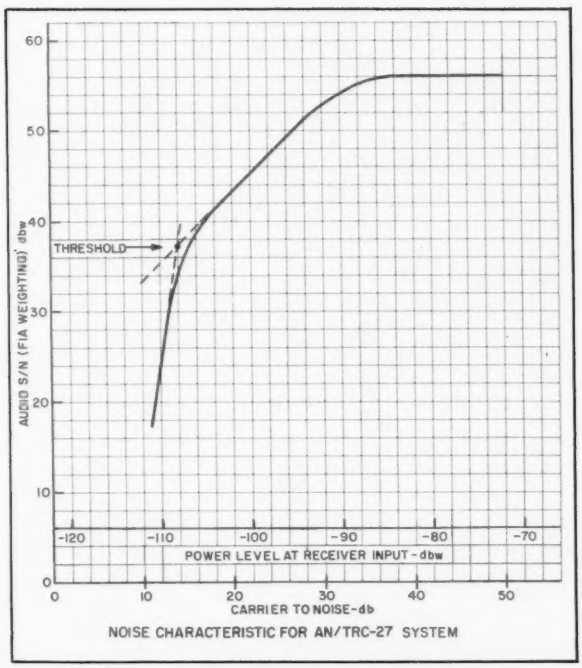

Figure 10

Figure 11

MULTIPLEXER

The multiplexer (Figure 11) contains complete line-terminal facilities for four voice circuits with provisions for receiving and transmitting 20-cycle ringing. The front panel of the multiplexer incorporates four identical plug-in modulator-demodulator units called modems. The common circuits perform the basic system timing, synchronization and pulse shaping, and supply the ringing power necessary to

Photo courtesy of U.S.M.C.

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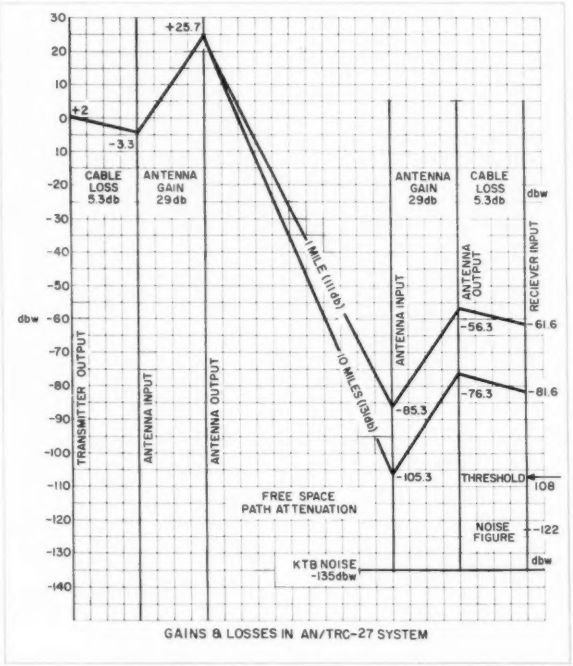

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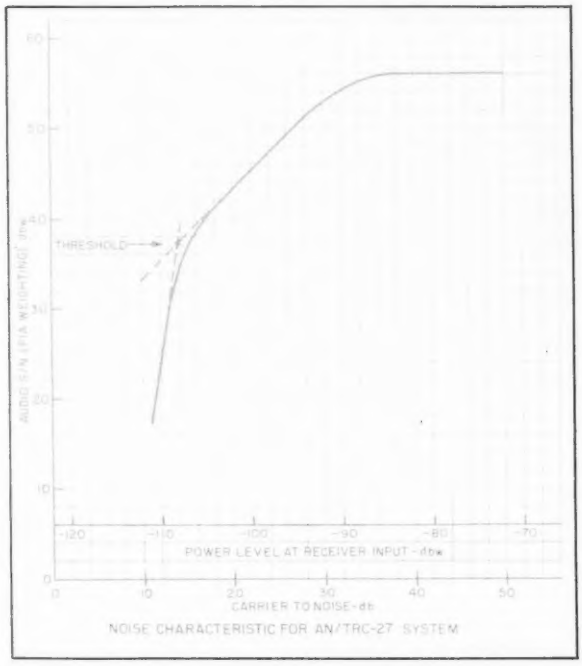
AUDIO S/N (F1A WEIGHTING) db
THRESHOLD
POWER LEVEL AT RECEIVER INPUT - dbw
CARRIER TO NOISE - db
NOISE CHARACTERISTIC FOR AN/TRC-27 SYSTEM

Figure 10

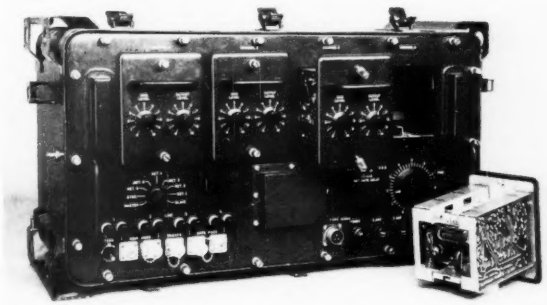

Figure 11

MULTIPLEXER

The multiplexer (Figure 11) contains complete line-terminal facilities for four voice circuits with provisions for receiving and transmitting 20-cycle ringing. The front panel of the multiplexer incorporates four identical plug-in modulator-demodulator units called modems. The common circuits perform the basic system timing, synchronization and pulse shaping, and supply the ringing power necessary to

ring two field telephones over five miles of field wire. Two multiplexers may be connected into a single system giving a total channel capacity of eight 2-way circuits.

Channel-timing commutation is obtained by using 125-microsecond, hermetically sealed, lumped-constant delay lines. One of each delay line is used for receiving and transmitting. The output of the multiplexer is a video pulse train containing eight 0.5 microsecond channel pulses and a synchronizing pulse pair every 125 microseconds. Connection of input and output pulses is made by cable to the transmitter-receiver unit.

Among the design features of the multiplexer is the use of high reliability subminiature tube-type CK6021 in the plug-in modems. Five of these tubes, soldered permanently into printed-wiring subassemblies, are used in each modem.

TRANSMITTER

The input to the transmitter is derived from the multiplexer. The transmitter portion of the T/R unit consists of a four-stage pulse modulator driving a 6280 planar-triode oscillator. The oscillator delivers a pulse power of 3 watts to a ferrite isolator and three-section transmitter filter with a net power output at the terminal of 1.5 watts. The oscillator consists of an adjustable tuned-grid, tuned-plate, re-entrant type microwave cavity operating over the frequency range from 4400-5000 mc.

To achieve the requirements of frequency stability over the temperature range, careful choice of cavity materials was required. The body of the oscillator cavity is constructed of stainless steel, with aluminum being used for the plate-tuning assembly. The grid-grounding structure and associated grounding pins are made of Invar, and provide a high degree of rigidity with respect to the oscillator body.

A calibrated wavemeter with an accuracy of better than 1 mc is provided as an aid in setting up the transmitter frequency to any one of 30 arbitrarily predetermined channel allocations. The transmitter, filter, and wavemeter are continuously tunable over the 4400-5000 mc range by means of front panel controls. Facilities are also provided to permit front panel indication of pulse-power output.

RECEIVER

The receiver and video amplifier chassis is contained in the T/R unit. The receiver is a superheterodyne with a balanced-type mixer using a pair of low-noise 1N21C crystals. A three-cavity tunable preselector filter having a 20 mc bandwidth provides excellent pre-selection and image-frequency rejection. It also serves to isolate the receiver from cross-coupling effects due to radiation from the local transmitter. The AGC system was designed to permit a dynamic range better than 50 db to allow for operation with stations separated between 0.5 and 10 miles, as well as for rapid fades. Twenty db of excess gain over the normal requirements is provided to allow for tube aging.

An AFC system with a lock-in range of approximately 10 mc is provided. In the absence of signal, the local oscillator searches a frequency band of 10 mc for the incoming transmission. The choice of 10 mc permits a broad enough lock-in range to follow frequency variations of the remote transmitter and any change in voltage sensitivity of the local oscillator.

The video amplifier portion of the receiver contains a slicer circuit to reduce noise fluctuations. This reduction is accomplished by taking a 10% slice of the received pulse at about half-amplitude after detection,

Figure 12

and by amplifying the resultant signal to a uniform limit-level. The output of the receiver is a video pulse train which is fed to the multiplexer for demodulation.

The local oscillator is a 2K22 single-cavity reflex klystron which is tuned manually from the front panel. During normal operation, the klystron repeller receives its control voltage from the AFC circuit. The klystron output is connected to the balanced mixer through a variable attenuator.

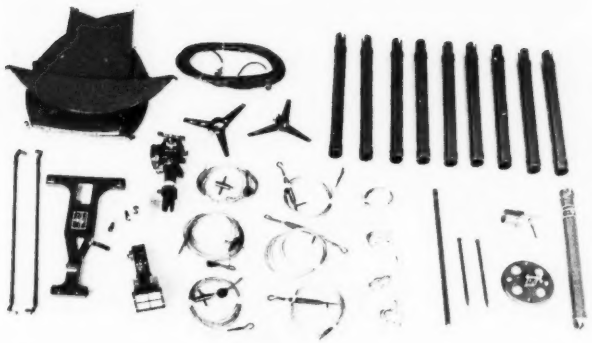

Figure 13

ANTENNA ASSEMBLY

The antenna assembly (Figures 5 and 12) consists of a 20-foot aluminum mast, an antenna reflector, off-center feed horn, guy wire, transmission lines, and hardware. The aluminum mast and molded reflector are sectionalized to permit their being packed for man-carry in the watertight case. The nine identical sections of the mast are designed to nest into one another (Figure 13). When assembled, the mast is a guyed structure secured by three stress wires with three additional anchored guy wires supporting the over-all antenna structure. The entire antenna can be assembled and erected by two men in less than 15 minutes. Facilities for easy manual positioning both in elevation and in azimuth are included.

The antenna proper is made up of a 30-inch diameter paraboloidal reflector with an off-center diplexing horn capable of simultaneous use for both transmission and reception. Diplexing is achieved by utilizing two probes mounted at right angles to each other, and separately fed so as to excite horizontally and vertically polarized waves for each direction of radio transmission. The entire mast assembly is designed to permit satisfactory system operation in a 60-mph wind, and will withstand winds up to 90 mph.

TABLE 2
TECHNICAL SUMMARY OF
RADIO SET AN/TRC-27

Radio Frequency	4400-5000 mc (tunable)
Type of RF Emission	A.M.
Type of Modulation	Pulse Position Modulation
Frequency Stability	0.05%
Pulse-power Output	1.5 watts
Receiver Noise Figure	13 db
Receiver Bandwidth at 3 db	8.5 mc
Antenna Height	22 feet
Antenna Size	30-inch paraboloid
Antenna Gain	29 db
Fade Margin (30 miles line-of-sight)	16 db
Wind Loading	60 mph (operating)
Number of Channels	8
Audio Input Level (2W)	0 dbm
Audio Output Level (2W)	−6 dbm
Input Impedance	600 ohms (balanced)
Frequency Response	300-3500 cycles
Cross talk (below 100% modulation)	55 db
Signal-to-Noise	56 db (F1A weighted)
Distortion	3% maximum
Operating Conditions:	
Temperature	−54°C to +65°C
Relative Humidity	Up to 95%
Primary Power	115V ± 5%, 400 cycles
Power Consumption	500 watts

POWER SOURCES

Power for operating one AN/TRC-27 requires a 500-watt source of 115V, 400-cycle, single-phase AC. For the man-pack system, a lightweight four-stroke-cycle gasoline engine driving a permanent magnet AC generator is furnished.

Prototype evaluation of the AN/TRC-27 was made by the Marine Corps Equipment Board at Quantico, Virginia, during 1957 where over 1000 hours of continuous and trouble-free operation were achieved. Although designed to meet rigid military specifications of performance, ruggedness and light weight, Radio Set AN/TRC-27 offers the added feature of a terminal that compares favorably with commercial microwave relays as to cost per channel.

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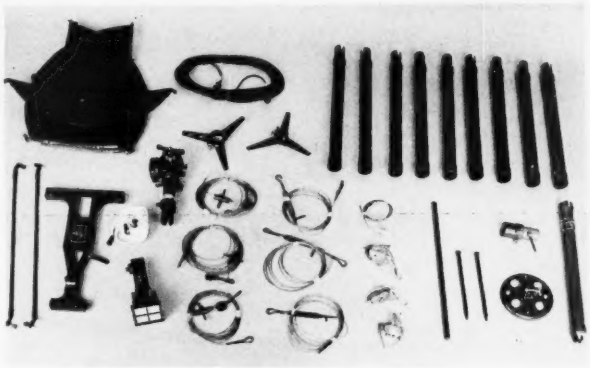

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RADIOISOTOPES
new tool for industry

R. V. Peirce
Research Division

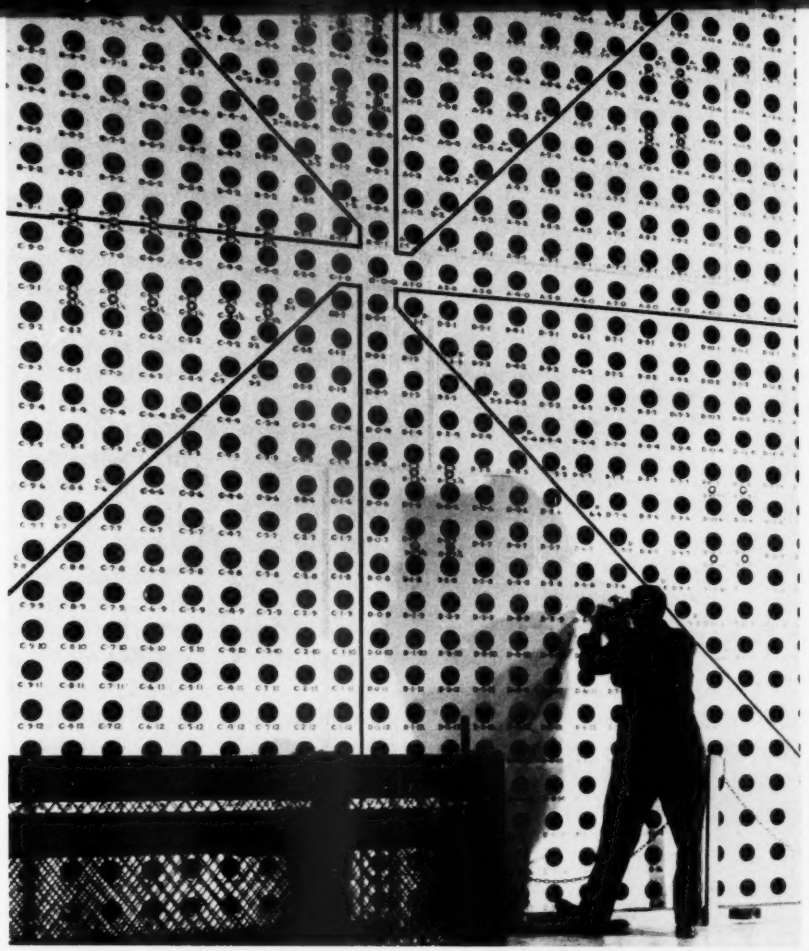
BECAUSE the sun happened not to shine in Paris in late February of 1896, a revolutionary new phenomenon of science was brought to light. Henri Becquerel, the distinguished French physicist, was investigating the effect of sunlight upon the luminescence of uranium salts. When the sun did not appear for several days, he halted his experiments and returned the photographic plates he was using to the darkness of a drawer, with thin crystals of uranium salt still in place upon the paper used to wrap the plates. Upon developing the plates, instead of the faint images he expected, Becquerel found intense silhouettes of the crystals. From this it could only be deduced that the uranium salt emits rays even without being exposed to sunlight, a property which Marie Curie several years later named radioactivity.

The radiations from uranium-bearing materials were of great interest to Marie and Pierre Curie, and in 1898 they undertook to measure them quantitatively. In their investigations they noted that some uranium-bearing minerals are much more radioactive than uranium itself, concluding that these minerals must contain some very active substances. After years of complex and laborious experiments, the Curies succeeded in isolating a highly radioactive new metal, which they called polonium, and the intensely active new element, radium. For nearly half a century, radium stood as the only material available for use in medical teletherapy.

Since the discovery of radium, more than forty other naturally occurring radioisotopes have been found. Together with the stable isotopes they make up a total of more than 300 isotopes found in nature. But man has produced far more radioisotopes than are found in nature, some 900 of them, by using nuclear reactors and particle accelerators.

Isotopes of an element have the same number of protons and electrons, but differ in the number of neutrons in the nucleus. Since ordinary chemical properties of a substance are essentially of electronic origin, all isotopes of an element behave in the same way chemically. Isotopes, however, differ greatly in nuclear properties, such as weight, radioactivity, and ability to undergo fission. A radioisotope is simply an isotope that has an unstable nucleus and decays, with the emission of radiation, into another isotope. The product of this decay may itself be radioactive and decay further. The process is continued until eventually a stable isotope is formed. The rate of decay is discussed in terms of half life, which is the time in which the strength of radioactivity decreases by one-half. The strength of radioactivity may be measured in terms of the curie, which is that amount of material in which 3.7×10^{10} nuclei decay each second. The curie is close to the activity of one gram of radium.

Most radioisotopes today are produced in reactors, either as fission products or through the bombardment of stable isotopes. The Atomic Energy Commission can, for example, produce 5-year (half life) cobalt-60 at the rate of 200,000 curies per year in its Savannah River reactors by irradiating ordinary cobalt-59 with neutrons. Recently the Commission completed, at Oak Ridge National Laboratory, a Multicurie Fission Products Pilot Plant that has a capacity for separat-



Materials to be irradiated are introduced through these holes in the south face of the Brookhaven reactor.

Photo courtesy of Brookhaven National Laboratory

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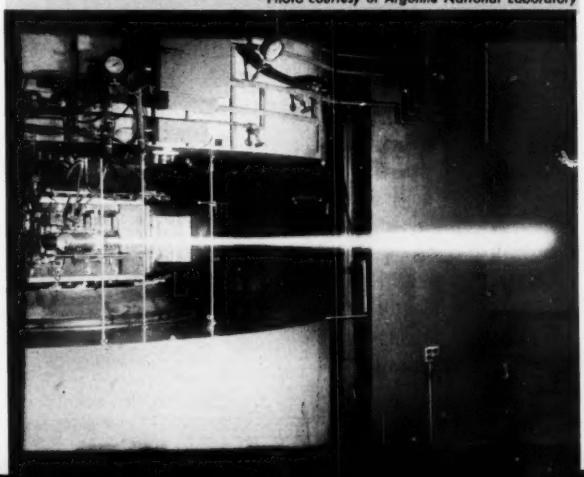
Beam of deuterons emerging from the acceleration chamber of a 60-inch cyclotron.

Photo courtesy of Argonne National Laboratory



In general, all applications of radioisotopes use them either as radiation sources or as tracers. The more important industrial uses as radiation sources include gauging and radiography. As tracers, radioisotopes are valuable not only because they emit radiation, which for this purpose need be only of low strength, but also because of their chemical identity with other isotopes of the same element. Radiation from radioisotopes is principally in the form of alpha particles, beta particles, and gamma rays. A radioactive atom generally decays by emitting an alpha or beta particle with or without gamma rays. Alpha particles are helium nuclei and are relatively not very penetrating; those emitted by radioactive nuclei can be stopped by a thin sheet of paper. Beta rays are electrons released by radioactive nuclei, and can travel through a few feet of air or a fraction of an inch of metal. Gamma rays are high energy electromagnetic radiations that have considerable penetrating power, an inch or more of metal being required to absorb them to such an extent that detection is difficult.

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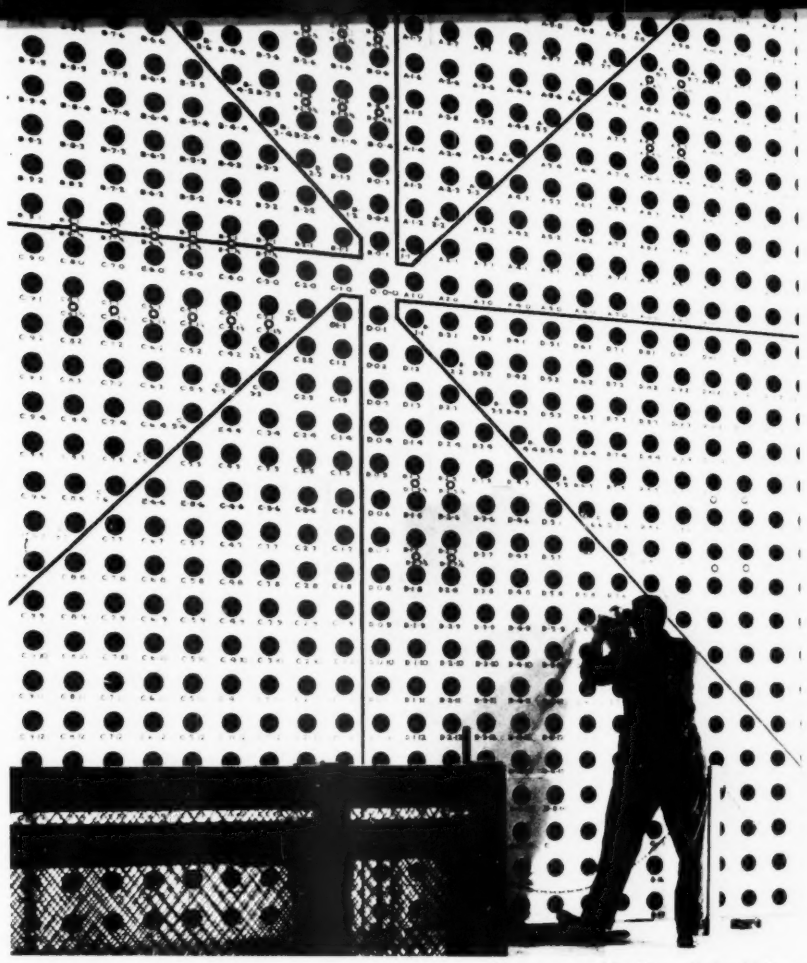

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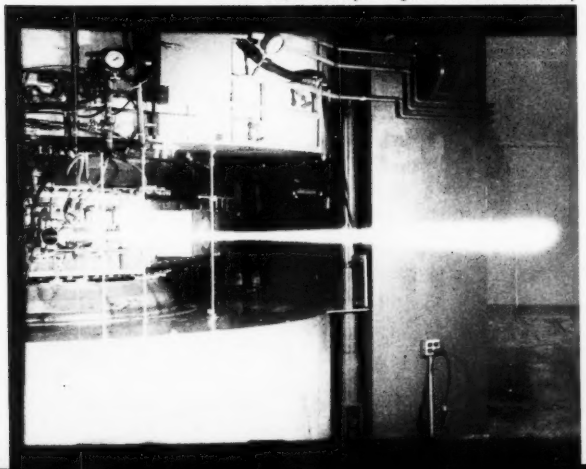

In general, all applications of radioisotopes use them either as radiation sources or as tracers. The more important industrial uses as radiation sources include gauging and radiography. As tracers, radioisotopes are valuable not only because they emit radiation, which for this purpose need be only of low strength, but also because of their chemical identity with other isotopes of the same element. Radiation from radioisotopes is principally in the form of alpha particles, beta particles, and gamma rays. A radioactive atom generally decays by emitting an alpha or beta particle with or without gamma rays. Alpha particles are helium nuclei and are relatively not very penetrating; those emitted by radioactive nuclei can be stopped by a thin sheet of paper. Beta rays are electrons released by radioactive nuclei, and can travel through a few feet of air or a fraction of an inch of metal. Gamma rays are high energy electromagnetic radiations that have considerable penetrating power, an inch or more of metal being required to absorb them to such an extent that detection is difficult.

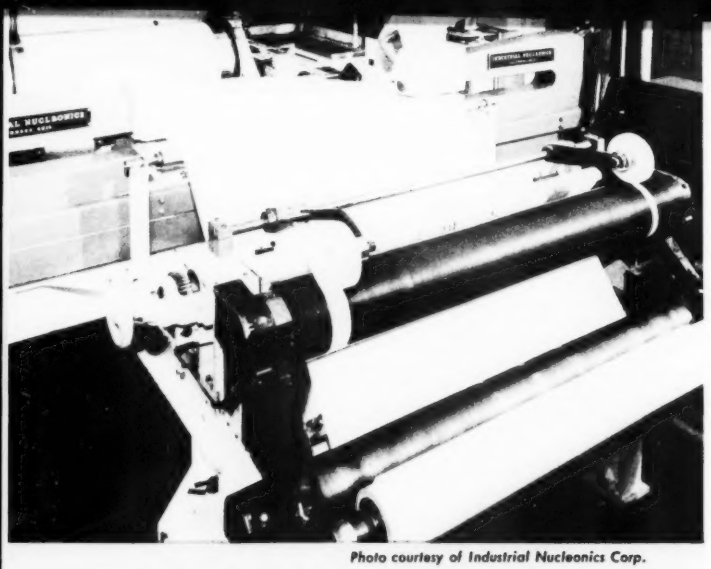

Photo courtesy of Industrial Nucleonics Corp.

Thickness gauge used in the production control of plastic sheeting.

The most common of all radioisotope applications are gauges, which are used to measure and control thickness, density, and liquid levels. Radioactive thickness gauges are useful for quickly and accurately measuring the thickness of a strip or a coating of material without touching or damaging it. This is frequently done in a continuous manner, with the information being fed back through a control unit that automatically adjusts important parameters. Such gauges reduce the amount of raw material and scrap, assure a more uniform product, and speed up operations. In measuring the thickness of a strip of material of known density, the radioactive source is placed on one side of the material and a radiation detector on the other. The amount of radiation that penetrates the material and is detected depends upon, and is therefore a measure of, its thickness. The thickness and density of the material to be measured determine whether a beta or gamma source is used and the energy of the source.

To measure the thickness of a coating, a radiation source may be placed on one side of the material and the detector on the other in certain cases. This may be done if the coating thickness is a substantial fraction of the thickness of the base stock, if the coating selectively absorbs X-ray radiation at a resonance corresponding to the energy of an available gamma source, or if the coating is a strong absorber of neutron radiation while the base is not. Frequently, a beta reflection gauge is used in which a beta source and detector are placed on the same side as the coating. The amount of beta radiation reflected back to the detector is a function and measure of the thickness of a coating of known density. One company, for example, uses a beta reflection gauge for measuring the thickness of zinc coatings on steel plates within a few minutes of their being withdrawn from the coating bath.

Using radioactive devices operating on the same principle as the thickness gauges, the density of a material of known thickness, or the level of a liquid in a closed vessel, may be measured. Density gauges are used in such diverse applications as determining the specific gravity of hydrocarbons, the amount of moisture in cement slurries, and, as a remotely operating aid in planning the use of hydroelectric power, the water content of snow cover in relatively inaccessible mountainous regions. When it is not desirable to penetrate a tank containing a liquid with indicator leads or piping, a liquid level gauge consisting of a radioactive source on one side of the tank and a detector on the other may be used to measure the height of the liquid through its effect on the amount of radiation that it permits to pass through the tank.

More than five thousand radioisotope gauges of various types have been licensed to date by the Atomic Energy Commission, and the number is rapidly increasing as more and more companies improve their products and cut costs with these devices. Users typically find that the gauges pay for themselves in less than a year, and net savings to American industry are now running to more than $150 million annually.

The use of radioisotopes for industrial radiography is, of course, not new. The nondestructive internal inspection of manufactured articles has long been important, and radium was employed to supplement X-ray machines for this purpose. Although radium was too expensive to compete with X-ray generators at low energies, it emits gamma radiation of high equivalent X-ray energy and was competitive at the higher energies. With the advent of low-cost artificial radioisotopes, however, there is little justification for the continued use of radium in radiography.

The radioisotopes most commonly used in radiography today include 5-year cobalt-60, 30-year cesium-137, and 74-day iridium-192, in order of decreasing gamma ray energy. The higher the energy, the more effective the radioisotope is for radiographing thick material, but the greater is the minimum thickness of material that it can satisfactorily radiograph. These three radioisotopes together cover a range of thickness of steel, for example, of about one-half inch to seven inches. An effort is being made to develop lower energy gamma sources, such as thulium-170 and cerium-144, for the radiography of thinner sections, which presently require the use of X-ray machines.

In some ways, X-ray machines are more convenient than radioactive sources. They are of higher intensity, and therefore can radiograph more rapidly. Their energy is adjustable, and can be regulated to suit the

material being radiographed. And an X-ray machine can be completely shut off. But over the range of thickness for which they are applicable, radioisotopes offer a number of distinct advantages over X-ray apparatus. They are highly portable and independent of power, which is important in field work. Because they emit omnidirectional radiation, they can be used to radiograph several pieces simultaneously, whereas the beam area of an X-ray machine is relatively small. Since they are small in size, radioisotopes can be inserted through small openings and can be used from within to radiograph an entire spherical vessel or circumferential weld in one exposure. And finally, radiographs made using a radioactive source are generally less expensive than those made with an X-ray machine.

More than six hundred companies in the United States are now using radioisotopes in radiographic testing and, according to the AEC, are thereby saving more than $50 million a year. More important than the direct economic benefits, radioisotopes have done many jobs that could not otherwise have been so effectively accomplished. For example, in the nuclear power plant of the *USS Nautilus*, thousands of welds in the primary coolant system were checked quickly with cobalt-60. It is difficult to place a monetary value on the contribution this technique made to expediting construction and to the integrity of the plant.

As tracers, radioisotopes have found a wide variety of uses in almost every type of industry. Because both behave in the same way chemically, a radioactive isotope may be substituted for a nonradioactive isotope of the same element in a material, and its progress followed through the most complex processes by tracing its radiation. The tracer may be added by mixing a radioisotope with the material or by irradiating the material in a reactor.

Radioactive tracers are used in corrosion and wear studies, determining fluid flow characteristics, chemical analysis, and research. Piping and pressure vessels have been checked for corrosion, and bearings and machine tools for wear, by making them radioactive and measuring the activity of the corrosion or wear product. In the process industries, the blending of materials is monitored by incorporating a radioisotope in one of the components of the blend and determining when the mix is uniformly radioactive. The amounts of impurities present to the extent of less than one part in a billion in semiconductor materials are being determined by irradiating the materials and measuring the characteristic radiation of the impurities which are thereby activated, a technique termed activation analysis. In research, tracers are being used in studies of solid diffusion, ion sorption on a solid surface, and vapor pressure of metals.

Besides gauging, radiography, and tracer applications, radioisotopes have many other uses. These include their application in atomic batteries and ionization sources, for sterilization and inducing chemical reactions, and in luminescent materials. As a source of power, radioisotopes are in general expensive, but practical atomic batteries of extremely low power output have been produced. One such battery, using beta-emitting promethium-147, is capable of powering a wrist watch for five years. It is believed that, with further development, atomic batteries will be very useful, in conjunction with transistor circuitry, as power sources for electronic systems in missiles and satellites. At Raytheon, an investigation is being made of the possibility of using a radioisotope for heating cathodes.

The ability of radiation to produce ionization is commonly taken advantage of in static eliminators and electron tubes. Radioisotopes maintain gaseous microwave switching tubes in a state of partial preionization to insure rapid triggering. Ionizing radiation, because of its ability to destroy living organisms, is capable of sterilizing food and drug products,

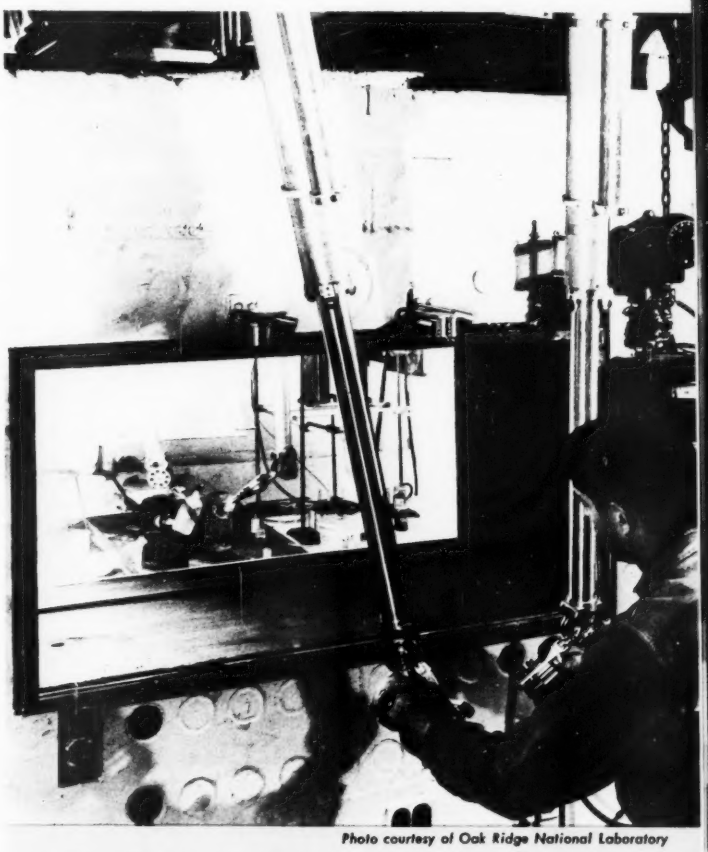

Photo courtesy of Oak Ridge National Laboratory

Remote control manipulators used in the preparation of radioactive materials.

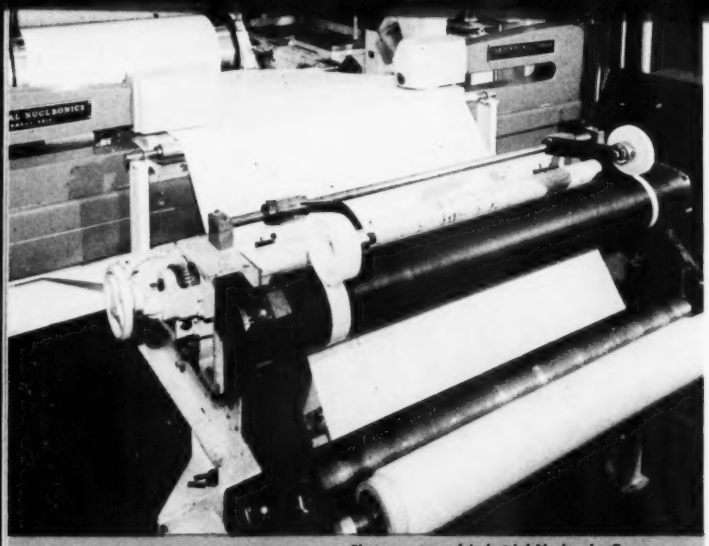

Photo courtesy of Industrial Nucleonics Corp.

Thickness gauge used in the production control of plastic sheeting.

The most common of all radioisotope applications are gauges, which are used to measure and control thickness, density, and liquid levels. Radioactive thickness gauges are useful for quickly and accurately measuring the thickness of a strip or a coating of material without touching or damaging it. This is frequently done in a continuous manner, with the information being fed back through a control unit that automatically adjusts important parameters. Such gauges reduce the amount of raw material and scrap, assure a more uniform product, and speed up operations. In measuring the thickness of a strip of material of known density, the radioactive source is placed on one side of the material and a radiation detector on the other. The amount of radiation that penetrates the material and is detected depends upon, and is therefore a measure of, its thickness. The thickness and density of the material to be measured determine whether a beta or gamma source is used and the energy of the source.

To measure the thickness of a coating, a radiation source may be placed on one side of the material and the detector on the other in certain cases. This may be done if the coating thickness is a substantial fraction of the thickness of the base stock, if the coating selectively absorbs X-ray radiation at a resonance corresponding to the energy of an available gamma source, or if the coating is a strong absorber of neutron radiation while the base is not. Frequently, a beta reflection gauge is used in which a beta source and detector are placed on the same side as the coating. The amount of beta radiation reflected back to the detector is a function and measure of the thickness of a coating of known density. One company, for example, uses a beta reflection gauge for measuring the thickness of zinc coatings on steel plates within a few minutes of their being withdrawn from the coating bath.

Using radioactive devices operating on the same principle as the thickness gauges, the density of a material of known thickness, or the level of a liquid in a closed vessel, may be measured. Density gauges are used in such diverse applications as determining the specific gravity of hydrocarbons, the amount of moisture in cement slurries, and, as a remotely operating aid in planning the use of hydroelectric power, the water content of snow cover in relatively inaccessible mountainous regions. When it is not desirable to penetrate a tank containing a liquid with indicator leads or piping, a liquid level gauge consisting of a radioactive source on one side of the tank and a detector on the other may be used to measure the height of the liquid through its effect on the amount of radiation that it permits to pass through the tank.

More than five thousand radioisotope gauges of various types have been licensed to date by the Atomic Energy Commission, and the number is rapidly increasing as more and more companies improve their products and cut costs with these devices. Users typically find that the gauges pay for themselves in less than a year, and net savings to American industry are now running to more than $150 million annually.

The use of radioisotopes for industrial radiography is, of course, not new. The nondestructive internal inspection of manufactured articles has long been important, and radium was employed to supplement X-ray machines for this purpose. Although radium was too expensive to compete with X-ray generators at low energies, it emits gamma radiation of high equivalent X-ray energy and was competitive at the higher energies. With the advent of low-cost artificial radioisotopes, however, there is little justification for the continued use of radium in radiography.

The radioisotopes most commonly used in radiography today include 5-year cobalt-60, 30-year cesium-137, and 74-day iridium-192, in order of decreasing gamma ray energy. The higher the energy, the more effective the radioisotope is for radiographing thick material, but the greater is the minimum thickness of material that it can satisfactorily radiograph. These three radioisotopes together cover a range of thickness of steel, for example, of about one-half inch to seven inches. An effort is being made to develop lower energy gamma sources, such as thulium-170 and cerium-144, for the radiography of thinner sections, which presently require the use of X-ray machines.

In some ways, X-ray machines are more convenient than radioactive sources. They are of higher intensity, and therefore can radiograph more rapidly. Their energy is adjustable, and can be regulated to suit the

material being radiographed. And an X-ray machine can be completely shut off. But over the range of thickness for which they are applicable, radioisotopes offer a number of distinct advantages over X-ray apparatus. They are highly portable and independent of power, which is important in field work. Because they emit omnidirectional radiation, they can be used to radiograph several pieces simultaneously, whereas the beam area of an X-ray machine is relatively small. Since they are small in size, radioisotopes can be inserted through small openings and can be used from within to radiograph an entire spherical vessel or circumferential weld in one exposure. And finally, radiographs made using a radioactive source are generally less expensive than those made with an X-ray machine.

More than six hundred companies in the United States are now using radioisotopes in radiographic testing and, according to the AEC, are thereby saving more than $50 million a year. More important than the direct economic benefits, radioisotopes have done many jobs that could not otherwise have been so effectively accomplished. For example, in the nuclear power plant of the *USS Nautilus*, thousands of welds in the primary coolant system were checked quickly with cobalt-60. It is difficult to place a monetary value on the contribution this technique made to expediting construction and to the integrity of the plant.

As tracers, radioisotopes have found a wide variety of uses in almost every type of industry. Because both behave in the same way chemically, a radioactive isotope may be substituted for a nonradioactive isotope of the same element in a material, and its progress followed through the most complex processes by tracing its radiation. The tracer may be added by mixing a radioisotope with the material or by irradiating the material in a reactor.

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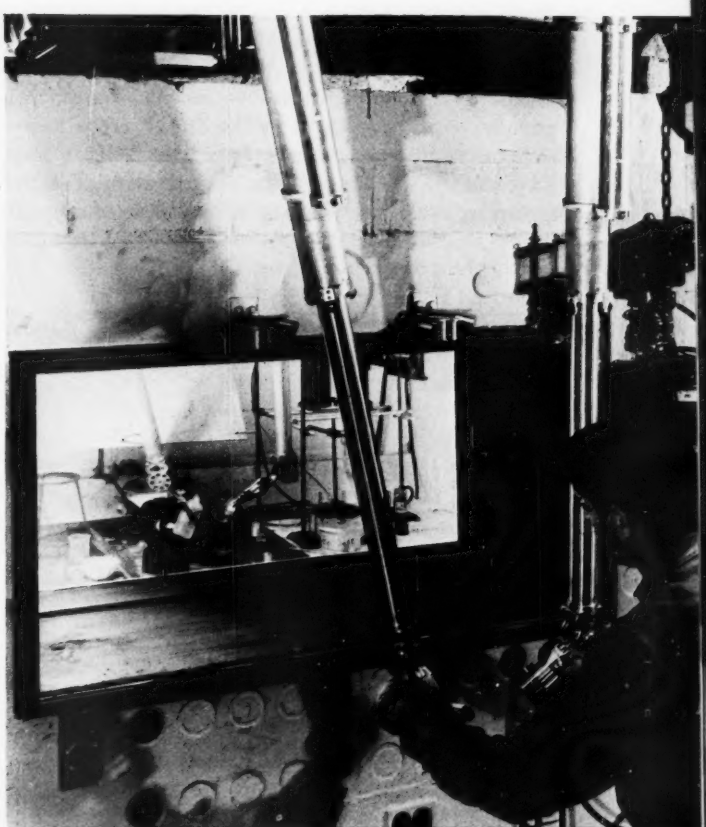


Photo courtesy of Oak Ridge National Laboratory

Remote control manipulators used in the preparation of radioactive materials.

and has the advantage of being able to do so without significantly raising their temperature. The effect of radiation on food is not sufficiently well understood to make radiation food preservation generally practicable at the present time, and the processing of drug products using radioisotope radiation is not yet economic. But drugs and medical supplies are already being sterilized on a commercial basis using the high intensity electron beams of the Van de Graaff particle accelerators. In chemistry, ionizing radiation is used to initiate certain reactions, such as polymerization.

The use of radioisotopes in luminescent materials is a familiar application. Until recently, only naturally occurring radioisotopes could be used, but they are gradually being supplanted by those produced artificially. Among the artificial radioisotopes are those that emit pure beta radiation, which is less hazardous to personnel than the gamma radiation and causes less deterioration to phosphorescent material than the alpha radiation of natural sources.

Those are some of the more important jobs given radioisotopes by the five thousand organizations specifically licensed to use them in the United States. To these users the AEC has sent, in the last decade, more than 100,000 shipments of isotopes totalling over 200,000 curies of activity.

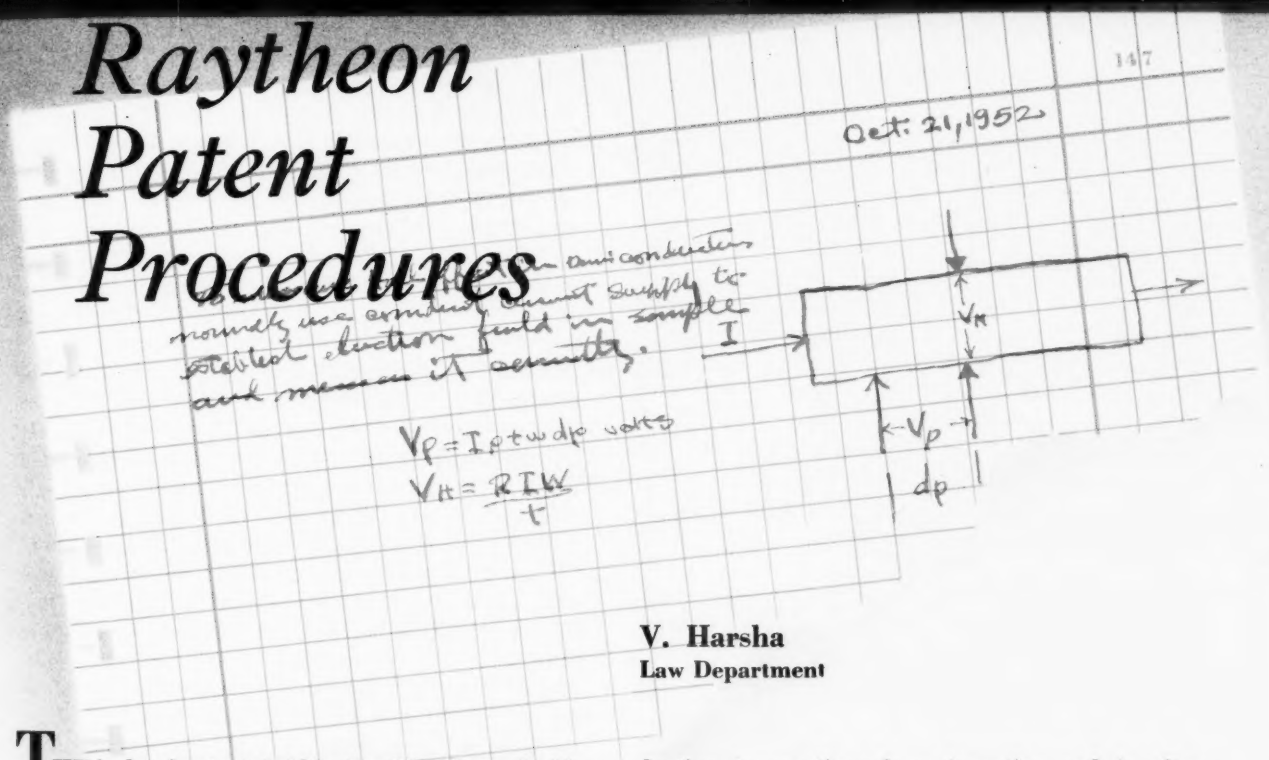
All persons or organizations in this country who possess reactor-produced radioisotopes must have a byproduct material license from the AEC Isotopes Extension. (The Commission has no jurisdiction over accelerator-produced or natural radioisotopes.) The Isotopes Extension itself does not sell or distribute radioisotopes. Reactor-produced radioisotopes are available, as described in their catalogs, from Oak Ridge National Laboratory and from Brookhaven National Laboratory. In addition, an organization may have its own material irradiated in a reactor or cyclotron by these and other AEC laboratories, if such service is not commercially available. Natural and cyclotron-produced radioisotopes, as well as reactor-produced radioisotopes, are available from the more than one hundred commercial organizations named in *Suppliers of Isotope Materials and Services*, a listing available from the AEC Office of Industrial Development.

The production and utilization of radioisotopes in this country are increasing rapidly, as industry, medicine, and agriculture discover their manifold utility. The Atomic Energy Commission has estimated that savings to industry alone, through the use of radioisotopes, have jumped fivefold in the last five years to nearly half a billion dollars a year. Their widespread use is the first extensive peacetime application of atomic energy and, despite the greater publicity given to nuclear power, is the most important use to date. But the enormous potential of these newly available materials has hardly begun to be tapped. It is estimated, for example, that the market for radioisotope thickness gauges is less than ten per cent saturated, and this is one of the older uses. It is evident, therefore, that radioisotopes will become increasingly a part of the equipment of industry.

Papers & Publications

S. L. Blum and M. H. Sirvetz	"Magnetic Resonance Studies in the Reaction of Nickel Cobalt Ferrite"
C. Bowness	"Microwave Ferrites and Their Application"
P. H. Fowler	"A Rugged Wide Band Shaker for Component Evaluation"
P. A. Grace	"Design of a Stereo Control Center"
R. C. Hergenrother and E. C. Scheffler	"A Metal-Ceramic 5-Watt X-Band Traveling Wave Tube"
L. Neuringer	"Effect of Pressure on the Infrared Absorption of Semiconductors"
J. R. Patel and J. Mullen	"Control of Solute Concentration in Crystals Grown from the Melt"
A. Phillips	"Tooling for Precision Depth Hobbing"
P. A. Rizzi	"Ferrite Modulators"
P. A. Rizzi	"Microwave Properties and Applications of Ferrite Rotators"
D. M. Rush	"Effective Control of Change Orders and Missile Production"
E. Schloemann	"Ferromagnetic Resonance in Polycrystals"
E. Schloemann	"Ferromagnetic Resonance in Polycrystalline Ferrites with Hexagonal Crystal Structure"
A. H. Smith	"Preparation of SiC Crystals"
W. S. Smith and F. Zawada	"A 3-Megawatt, 15-Kilowatt S-Band Amplitron"
W. A. Whitcraft, Jr.	"Aircraft Reflections in VHF Communications System"
S. P. Wolsky	"Studies of Semiconductor Materials Using a Vacuum Microbalance"

Raytheon Patent Procedures



V. Harsha
Law Department

THE body of patents held by Raytheon is a valuable property right whose value should increase as the Company grows. This increased value must result from a greater number of high-quality patents. The number and quality of patents obtained depends greatly upon the adherence of all concerned to an established procedure for recording patentable ideas and for obtaining patents when such action is warranted. The purpose of this article is to describe this procedure in simple terms and to acquaint interested persons with the steps involved in the processing of patents within Raytheon.

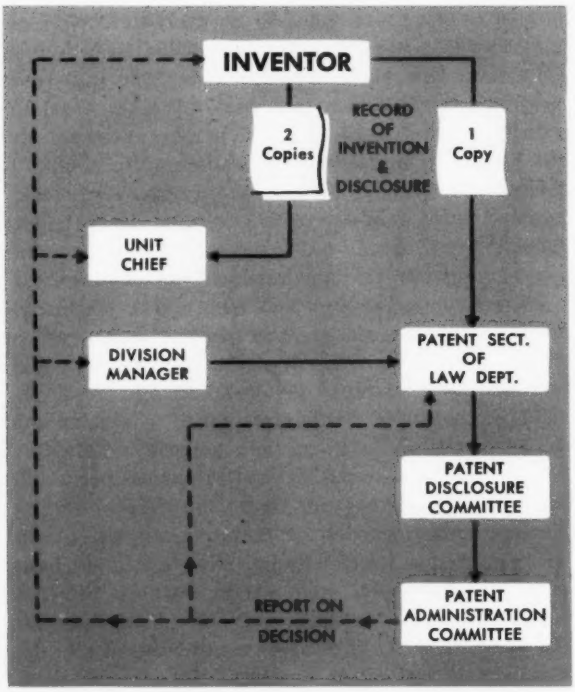
The first step in this established procedure stems from the necessity for proper record of an invention. The proper medium for recording an invention is the Engineering Notebook, which is issued to all Raytheon engineers. The Engineering Notebook is not only a valuable aid to the engineer in recording technical progress but, from the point of view of patents, assumes added value when it is realized that an inventor is often not aware of the patentability of an idea at the time he is entering it in the Notebook. The Notebook proves invaluable when subsequent events indicate that an idea which at first glance was not apparently an invention is actually patentable.

Notebook entries should be written in ink and should cover all work done on an invention including details of construction and descriptions of tests performed. The Notebook pages describing inventions should be witnessed by a fellow worker capable of understanding the invention. A properly kept Notebook is the best proof of the dates of inception and reduction to practice of an invention and is often accepted as such by the U. S. Patent Office.

When an inventor has what he believes to be an invention recorded in his notebook he should complete the Record of Invention Form. The form should be filled out in triplicate along with a disclosure of the invention, also in triplicate. The disclosure is a description (with sketches where practicable) to be used as a communication between the inventor and the committees which are to consider his invention for patentability. Thus, each disclosure should be complete enough to permit a proper evaluation. The disclosure should describe the advantages of the invention and how it differs from what the inventor knows to be old.

One copy of the completed Record of Invention Form with the requisite disclosure is sent directly to the Patent Section of the Law Department. This copy alerts the Patent Section to the fact that a possible invention has been made and provides for future checks on progress toward a patent. When it is received in the Patent Section, the disclosure is assigned a number. However, a number will not be assigned if a disclosure does not accompany the Record of Invention Form. The inventor is notified of receipt of the form by the Patent Section and in the event the disclosure is incomplete he will be so informed. An incomplete disclosure will require completion to warrant further consideration.

Two copies of the Record of Invention Form and the disclosure are sent to the inventor's unit chief. This arrangement keeps the chief informed of inventions occurring in his area, and also affords him an



opportunity to comment. These comments are normally directed to the novelty of the disclosure and its possible present or future utility. The unit chief also comments on the present use of the invention at Raytheon and any advantages it possesses over what is known in the field. The unit chief forwards his comments along with the two copies of form and disclosure to the Division Manager who adds comments of a similar nature. The Division Manager then forwards the disclosure and form, with comments, to the Patent Section. The case is now ready for consideration by the various Patent Committees.

The complete disclosures and Record of Invention Forms are now assigned on the basis of subject matter to an individual Patent Disclosure Committee for consideration. Each committee is composed of Raytheon engineers who are familiar with a particular field, such as semiconductors, microwave tubes, transistors, etc., and who are also aware of Company policy on patents. Fifteen of these Patent Disclosure Committees are necessary to cover all the operations of Raytheon engineers. The Patent Disclosure Committee studies the invention disclosures individually, including a separate investigation of the facts and the potentialities of each invention. The Patent Disclosure Committees may contact the inventor as to certain aspects of his disclosure in order to properly evaluate the invention, and may also ask him to be present when his invention is considered. A Patent Advisor from the Patent Section advises the Committees as to the probable patentability of each disclosure and also serves as secretary to each of these Committees. After due consideration the Patent Disclosure Committees make recommendations as to whether or not a disclosure should be approved or disapproved for the filing of a patent application. A written report on the recommendations and the reasons for such recommendations is made by the Patent Advisor of each Committee.

All patent disclosures, along with the recommendations of the Patent Disclosure Committee, are then submitted to the Patent Administration Committee for consideration. This committee is appointed by the President to review the bases on which individual disclosures have been approved or disapproved by the Patent Disclosure Committees. When the Patent Administration Committee makes this review, the Chairman and the Patent Advisor of the Patent Disclosure Committee concerned are present. If necessary for the proper evaluation of a disclosure an inventor may also be present at this meeting. The Patent Administra-

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Semiconductor Devices and Circuits Peculiar to Semiconductors	*W. F. Leverton*
Microwave Tubes	*P. Derby*
Receiving, Special Purpose and Conventional Transmitting Tubes	*O. P. Susmeyan*
Microwave Components	*H. Scharfman*
Communications (other than home entertainment)	*J. H. Nye*
Radar and Missiles	*W. M. Hall*
Magnetic Products and Allied Equipment	*R. S. Quimby*
Electromechanical Devices, Computers, Controls, and Servos	*H. A. Miller*
Sonics	*L. Batchelder*
Microwave Heating and Associated	*F. H. Brooke, Jr.*
Industrial Products Not Otherwise Assigned	*L. J. Kramer*
General Research	*L. Davis, Jr.*
Santa Barbara	*S. D. Crane*
Oxnard	*J. Daly*
Bristol	*G. Garlow*

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When a disclosure has been approved for filing, an approval notice is sent the inventor informing him of the award of patent bonus. The bonus amounts to $50 to a single inventor, and $35 to each co-inventor if more than one inventor is involved in a single disclosure. This first bonus will be paid within 90 days from the date of the approval notice. An additional payment of $50 or $35, as the case may be, will be made at the time of the filing of the patent application in the U. S. Patent Office. The Patent Section will file a patent application as soon as possible after a disclosure has been approved.

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The inventor also has available to him a release procedure. After the disclosure has been disapproved either the first or second time by the Patent Administration Committee, the inventor may request a release of invention. Releases which are granted by Raytheon will vary with the circumstances surrounding the disclosure. The release is normally subject to the reservation to Raytheon of a non-exclusive royalty-free license to make, use, and sell the invention, the right to sublicense existing and future licensees of Raytheon in the specific field, and any other rights deemed to be appropriate. Releases will not be granted to any inventor who has left the employment of Raytheon. If a release is refused for any reason the inventor will be given a detailed description of the reasons for the refusal. A disclosure made under a contract granting to the United States Government a royalty-free license will remain subject to this royalty-free license even if Raytheon releases the invention. All releases made under a government contract provide that a patent application must be filed in the U. S. Patent Office within three months from the date of release. This time limit is necessary inasmuch as reports of inventions made under government contracts must tell the government whether or not an application is going to be filed upon any disclosure. The release which Raytheon grants is to the disclosure information only and does not include any release of proprietary information of Raytheon.

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From what has been said above it is obvious that a good patent position for the Company can be attained only through the cooperation of many people. For this reason it is important that everyone, particularly the inventor, understand the many problems involved in securing patents and become familiar with the machinery for handling inventions within the Company. It is hoped that this article has answered some of the questions that arise in this area. Further information and answers to specific questions may be obtained from the Patent Section of the Law Department.

Inventions

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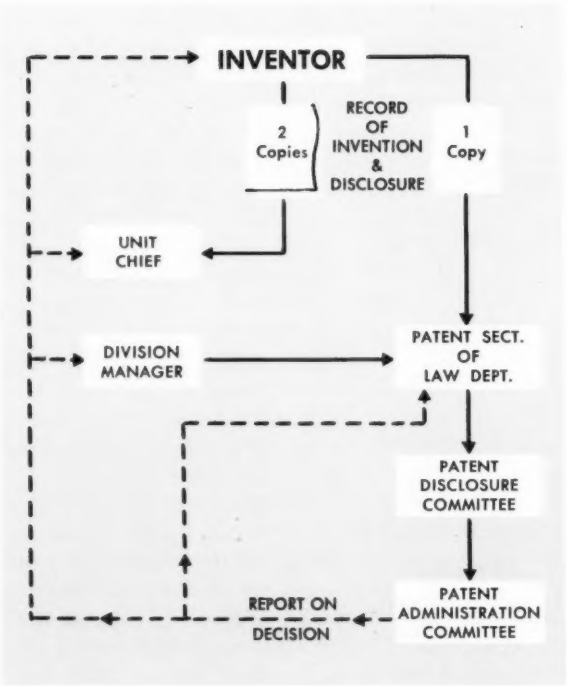
Name	*Field of Invention*
Robert Arnesen	Balanced Discriminator
Burton Askowith	Photoconductive Cells
Harold Asquith John Buckbee Alvin Luftman	2-Color, 2-Persistence Display
Karnig Berberian	Alloys for Semiconductor Devices
William Brennan Stephen Hannon	High Voltage Transformer
James Davis, Jr.	Transistor Noise Source
Edward Dench	Interdigital Line Matching
George Freedman Gerald Pighini	Emitter
George Freedman	Technique for Attaching to Base Region
Robert A. Fryklund	Spot Welding Head
Leon Greenberg	Semiconductor Devices
E. F. Keon G. T. Parish	Liquid Fuel Reactor
Claude Klein W. D. Straub	Semiconductor Device
Kurt Kramp	Narrowing Antenna Beamwidth
Kurt Kramp	Narrow Antenna Beamwidth System
Ralph Lanciano Jesse Shapiro	Method of Coating Wires
Richard Lang Robert Wyckoff	Ultra-Stabilization Systems
Alex MacDonald, Jr.	Masking of a Silicon Slice
John Osepchuk	"M" Type Traveling Wave Tubes
John Osepchuk Roy Paananen	Phase Shift Device
Robert Quimby B. W. Walunas	Method of Cooling
Burton Rawding	Magnetostrictive Transducer
Joseph Richard	High Frequency Transistors
William Ryen Paul Sullivan	Transistorized Diode
Arthur Rowe	Coaxial Cable
Arthur Slater	Microphonic Cancellation System
Hermann Statz	Spacistor Geometries
John Walsh Charles Winter	Antenna Array
Robert Wyckoff	Rate Energy Detector



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Burton Askowith	Photoconductive Cells
Harold Asquith John Buckbee Alvin Luftman	2-Color, 2-Persistence Display
Karnig Berberian	Alloys for Semiconductor Devices
William Brennan Stephen Hannon	High Voltage Transformer
James Davis, Jr.	Transistor Noise Source
Edward Dench	Interdigital Line Matching
George Freedman Gerald Pighini	Emitter
George Freedman	Technique for Attaching to Base Region
Robert A. Fryklund	Spot Welding Head
Leon Greenberg	Semiconductor Devices
E. F. Keon G. T. Parish	Liquid Fuel Reactor
Claude Klein W. D. Straub	Semiconductor Device
Kurt Kramp	Narrowing Antenna Beamwidth
Kurt Kramp	Narrow Antenna Beamwidth System
Ralph Lanciano Jesse Shapiro	Method of Coating Wires
Richard Lang Robert Wyckoff	Ultra-Stabilization Systems
Alex MacDonald, Jr.	Masking of a Silicon Slice
John Osepchuk	"M" Type Traveling Wave Tubes
John Osepchuk Roy Paananen	Phase Shift Device
Robert Quimby B. W. Walunas	Method of Cooling
Burton Rawding	Magnetostrictive Transducer
Joseph Richard	High Frequency Transistors
William Ryer Paul Sullivan	Transistorized Diode
Arthur Rowe	Coaxial Cable
Arthur Slater	Microphonic Cancellation System
Hermann Statz	Spacistor Geometries
John Walsh Charles Winter	Antenna Array
Robert Wyckoff	Rate Energy Detector

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